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BRUCE NGS 'B' UNIT 6
TORSIONAL VIBRATION TESTS

Report No. 90-207-K

J. Liska, F. Perricone
Plant Equipment Dynamics Section
Mechanical Research Department

ABSTRACT

A torsional vibration test of the Bruce NGS 'B' Unit 6 turbine-generator is described. The frequencies of the rotor torsional modes were measured using three strain gage torque collars attached to the shaft. The modes were also measured by demodulating an n/rev pulse signal generated by a toothed wheel attached to the rotor shaft on the generator end. The torsional excitation was supplied by creating a 4/rev negative phase sequence current in the generator winding.

job	file	date	report no.
740627-126-452	825.42	August 21, 1990	90-207-K

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EXECUTIVE SUMMARY

BRUCE NGS 'B' UNIT 6
TORSIONAL VIBRATION TESTS

Report No. 90-207-K

J. Liska, F. Perricone
Plant Equipment Dynamics Section
Mechanical Research Department

Failure of the Manshaan Unit 1 turbine-generator due to high cycle fatigue by torsional vibration raised concern about the similar Bruce NGS 'B' turbine units. The failure was attributed to excitation of a torsional vibration mode near the 4/rev operating frequency of 120 Hz. General Electric Company performed a torsional test on the Bruce 'B' Unit 8 turbine and identified torsional vibration modes at 118.9 Hz and 122.7 Hz.

This report presents the results of a similar torsional test performed on the Bruce 'B' Unit 6 turbine. Three strain gage torque collars and two n/rev toothed wheels were used to measure the torsional modes. The torsional vibrations were excited by producing and controlling the negative phase sequence current in the generator. The results from both units are compared so that any further action required to protect the units can be defined.

The results of this test showed that the Unit 6 turbine had torsional vibration modes at 118.125 and 122.125 Hz. It also demonstrated the validity of a much simpler toothed wheel technique to measure the frequency of torsional vibration modes. This technique demodulates an n/rev pulse signal from a toothed wheel attached to the rotor shaft.

Based on the variability of the torsional natural frequencies between Units 6 and 8, it is recommended that the torsional natural frequencies on Units 5 and 7 also be measured.

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To D. Cockayne
Bruce Engineering
Place Nouveau N18A4

Bruce NGS 'B' Unit 6 Torsional Vibration Tests

1.0 Introduction

In April, 1987 a torsional test of the Unit 8 steam turbine generator was conducted by General Electric Company Ltd. to determine the torsional natural frequencies of the rotor system. In November, 1989, a similar test was conducted on the Unit 6 turbine generator by the PED section of Mechanical Research. This report documents the results of the Unit 6 test and compares them to the Unit 8 test results.

The purpose of the test is to determine the precise location of the turbine generator rotor system torsional resonant frequencies near 120 Hz. The test is required to ensure that there is adequate separation between possible resonant frequencies near 120 Hz and the operating dynamic torque occurring at 120 Hz. An appropriate torsional stimulus was supplied to the rotor by creating a 4/rev oscillating electromagnetic phase sequence current in the generator armature winding. The magnitude of the oscillating torque is controlled by varying the negative phase sequence current.

In conjunction with the torsional test, the Electrical Research Department tested their frequency/negative phase sequence PALC relay. The results of its testing are presented in a separate report.

2.0 Test Method, Instrumentation and Measurements

A detailed description of the test procedure, instrumentation and measurements taken can be found in the attached work plan WP 89-6046 in Appendix A. A short summary of that document is provided here.

2.1 Test Method

The single phase torsional test used by GE on Unit 8 was also used here. The torsional vibration modes were excited by shorting one phase on the high voltage side of the generator and supplying current to the field windings with a welding machine. This combination causes a 4/rev oscillating electromagnetic phase sequence current to flow through two phases of the armature winding and interact with the magnetic flux in the field winding. The magnitude of the 4/rev torque induced is then proportional to the magnitude of the negative sequence current generated. The welding machine is used to finely control the negative sequence current.

During the test, the level of response of the rotor was closely monitored such that 8% I_2 was never exceeded. A special governor speed control was added to allow a slow 7 RPM/min rate of acceleration of the unit. This speed control was also used to accurately set specific speeds to tune in torsional frequencies.

The torsional natural frequencies of the sub- and super-synchronous modes of vibration were measured during slow run-ups and run-downs between 1500 RPM and 1900 RPM and at selected RPM holds.

2.2 Instrumentation

Three strain gage torque collars were mounted on the turbine-generator rotor shaft at bearings 4, 6 and 8 to measure the shaft torsional strains. Special radio frequency telemetry was used to power and receive signals from the torque collars. Each torque collar was equipped with two independent transmitters with separate signal conditioning and gain amplifiers. One telemetry receiver operated at 10.7 Mhz and the other at 16 Mhz. This redundancy allowed the correctness of each strain signal to be verified and protected against the possible loss of data due to instrument failure.

Figure 1 shows a photograph of one torque collar and its telemetry system installed on the rotor shaft. Figure 2 is a photograph of a pair of strain gages mounted on one side of the shaft before the collar is installed. A second pair of gages is mounted diametrically opposite to these. Four strain gages were mounted on the shaft near each bearing. Special weldable strain gages were used. The bridge circuit shown in Figure 3 links the gages together in a full Wheatstone bridge circuit so that the net signal output only responds to the torsional modes. This arrangement is insensitive to bending modes and is fully compensated for temperature effects. Figure 4 shows the location of the strain gages on the rotor shaft, under the telemetry collar.

Torsional frequencies were also determined by demodulating the n/rev pulse signals generated by the speed pickups on the front and rear TVMS toothed wheels. The speed pickup on the front wheel gave a signal with 160 pulses per revolution. The wheel on the generator end gave 154 pulses per revolution.

The electrical signals measured during the test were exciter voltage, exciter current and negative phase sequence current.

All the signals were amplified, conditioned and recorded on magnetic tape as shown in Figure 5.

Each torsional strain signal was recorded on two channels of the tape recorder. One channel was set to

accurately record large strains and the other for small strains, a factor of 5 less.

A real-time spectrum analyzer was used to continuously monitor the frequency content of each strain signal and measure the natural frequencies of each torsional mode. The TVI torsional vibration instrument measured the natural frequencies of the torsional modes that responded at the toothed wheels.

2.3 Measurements

Testing started with the turbine-generator on turning gear. All signals to the test equipment were verified. The strain signals from each of the torque collars was checked to insure they were all in phase. Following the required heat soak, the unit was accelerated to 1800 RPM at 60 RPM/min and held at that speed. The bearing vibrations and thermal expansions were measured and compared to normal operating conditions. At 1800 RPM, all signals to the instrumentation were again verified, including the relative phase between the torque strains at each bearing. The welding machine was then energized to provide a negative phase sequence current of 4%. When the I2 had stabilized and the magnitude of the torsion strains were confirmed to be acceptable, testing began.

The single phase torsion test was performed over a speed range of 1500 to 1900 RPM with a negative phase sequence current of 6%. Several run-ups and run-downs were required to accurately determine the location of each torsional vibration mode. For those modes that were difficult to excite, the I2 was increased to 8% for a short time.

For the dwell tests, the speed of the unit was set and held to correspond with each of the natural frequencies determined in the previous test. Sufficient time was spent at each mode to allow the response to grow and stabilize at its maximum amplitude. The shaft shear strains were monitored with an FFT spectrum analyzer to insure the response remained below preset safety limits.

When the dwell tests were completed, the turbine-generator was shut down. All the test instrumentation was removed, including the torque collars and strain gages. All the normal power leads were reconnected and the special speed governor removed. The unit was then returned to its normal operation condition.

3.0 Results and Discussion

3.1 Torque Collar Phase Check

The relative phases of the torsional strain signals between bearings 4, 6 and 8 were checked when the unit was placed on turning gear. Figures 6 and 7 show the initial torque placed on the rotor shaft just as it begins to turn. These figures show that both the 10.7 Mhz and 16 Mhz telemetry channels are in phase. The 10.7 Mhz channels are all 180° out of phase with the 16 Mhz channels due to the orientation of the strain gages.

This phase check was also performed at 1800 RPM, before the welding machine was turned on.

3.2 Torsional Vibration Modes

The torsional natural frequencies were identified from the playback and analysis of the acceleration and dwell tests recorded on tape. The strain signals were passed through a narrow band tracking filter before being analyzed on a Fast Fourier Transform analyzer. The analyzer was operated in the zoom mode with an analysis bandwidth from 95 Hz to 145 Hz. This corresponded to a frequency resolution of 0.125 Hz.

The torsional natural frequencies identified are shown in Table 1. These frequencies are in reasonably close agreement with the results reported by G.E. on Unit 8 and their analytic mode shape model results. The critical modes for Unit 6 that were located near 120 Hz are 118.125 Hz and 122.125 Hz.

The torsional response of the rotor shaft is shown in the 4/rev frequency spectrum plots, Figures 8 to 13. The first three figures show the torsional response at bearings 4, 6 and 8, respectively. Figure 11 shows the torsional frequencies observed on the generator end toothed wheel. Figures 12 and 13 show cascade plots of the torsional vibration measured on bearings 6 and 8 as the unit was accelerated.

Table 2 summarizes the relative phase of the torsional strain signals measured between each pair of bearings. This data allows the natural frequencies presented to be associated with a particular mode shape. The results observed on Unit 8 by G.E. are included for comparison. The phase of a response signal is measured relative to that of a reference signal using the transfer function capability of a multi-channel FFT analyzer.

3.3 Peak Response of Torsional Modes

The peak response of the torsional modes during the dwell tests are shown in Table 3. The negative phase sequence current was 8%.

4.0 Conclusions

4.1 The Unit 6 turbine-generator rotor modes closest to 120 Hz are at 118.125 and 122.125 Hz. These frequencies were determined from the torsional strain measurements at three locations on the rotor train and were also confirmed independently by demodulating an n/rev pulse signal produced by a toothed wheel attached to the shaft near the generator outboard end.

4.2 The Unit 6 torsional mode frequencies of 118.125 and 122.125 Hz are lower than the 118.9 Hz and 122.7 Hz modes measured on Unit 8 by General Electric. The differences of 0.9 and 0.6 Hz in the two modes gives an indication of the variability in the torsional natural frequencies which can be expected between the turbine-generators.

5.0 Recommendation

5.1 It is recommended that the torsional natural frequencies of the Unit 5 and 7 turbine-generator rotors be measured to determine their proximity to 120 Hz, considering the variability of the torsional natural frequencies for Units 6 and 8.

Approved :

for G.J. Clarke
Manager
Mechanical Research Dept.

Submitted :

JJ Liska
Engineer
Plant Equipment Dynamics Section
Mechanical Research Dept.

F. Perricone
Unit Head
Plant Equipment Dynamics Section
Mechanical Research Dept.

Bearing #4 (Hz)	Bearing #6 (Hz)	Bearing #8 (Hz)	Generator End Toothed Wheel (Hz)
-	98.0	98.125	-
115.625	115.625	115.625	115.625
117.125	117.000	-	117.125
118.125	118.125	-	118.125
122.125	122.125	122.125	122.125
125.125	125.125	-	-

Table 1: Torsional Vibration Modes

Measured Frequency (Hz)	Reference Signal	Response Signal	Relative Phase (degree)	Unit #8 Modes (G.E.)	
				Frequency (Hz)	Relative Phase
115.625	BRG #8	BRG #6	+174	116.3	out-phase
	BRG #8	BRG #4	+172		out-phase
	BRG #6	BRG #4	0		in-phase
117.125	BRG #8	BRG #6	+150	118.0	in-phase
	BRG #8	BRG #4	+48		out-phase
	BRG #6	BRG #4	-50		out-phase
118.125	BRG #8	BRG #6	+170	118.9	out-phase
	BRG #8	BRG #4	0		in-phase
	BRG #6	BRG #4	+156		out-phase
122.125	BRG #8	BRG #6	-173	122.7	out-phase
	BRG #8	BRG #4	+180		out-phase
	BRG #6	BRG #4	0		in-phase

Table 2: Torsional Vibration Modes Relative Phase Measurements

4/Rev Frequency (Hz)	Torsional Strains (pk-pk) I2 = 8%		
	Bearing #4	Bearing #6	Bearing #8
98.0	-	1.80	28.1
115.625	5.15	4.92	1.34
117.125	0.23	3.98	0.88
118.125	2.78	1.40	0.79
122.125	1.12	4.84	47.1
125.125	0.38	3.80	1.01

Table 3: Peak Response of Torsional Strains

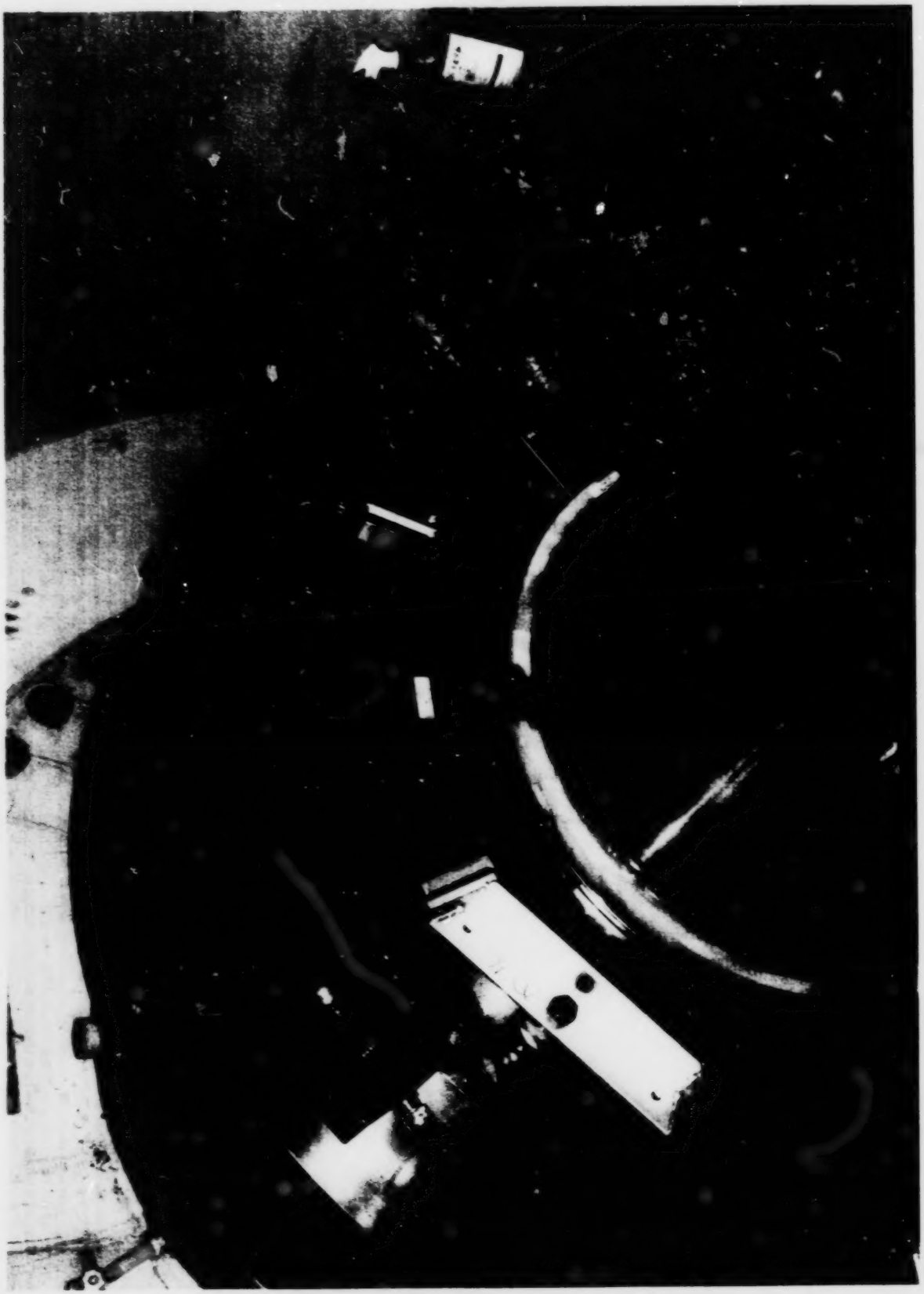


FIGURE 1

PHOTOGRAPH OF TORQUE COLLAR INSTALLED NEAR BEARING #6

FIGURE 2

CLOSE-UP OF ONE PAIR OF STRAIN GAGES MOUNTED ON SHAFT

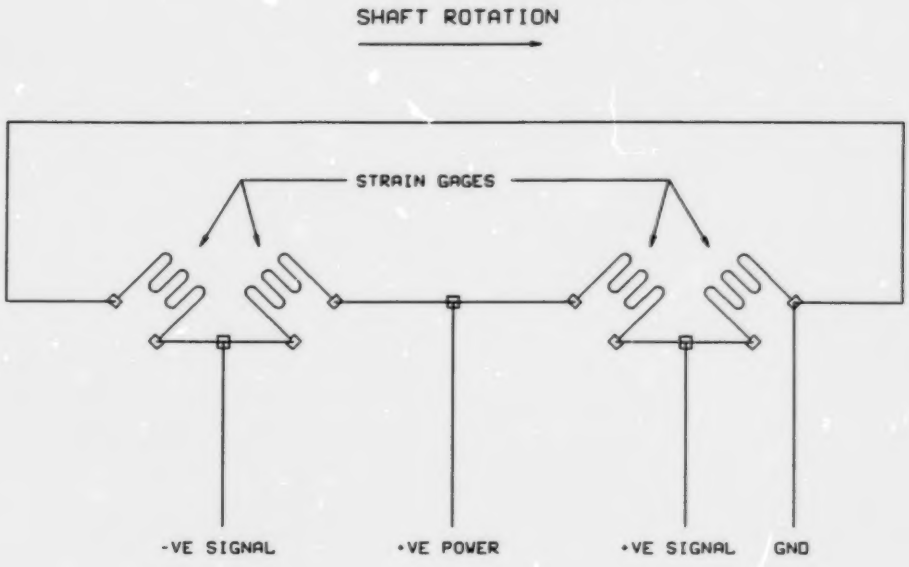


Figure 3: Full Whetstone Bridge Circuit Linking Strain Gages

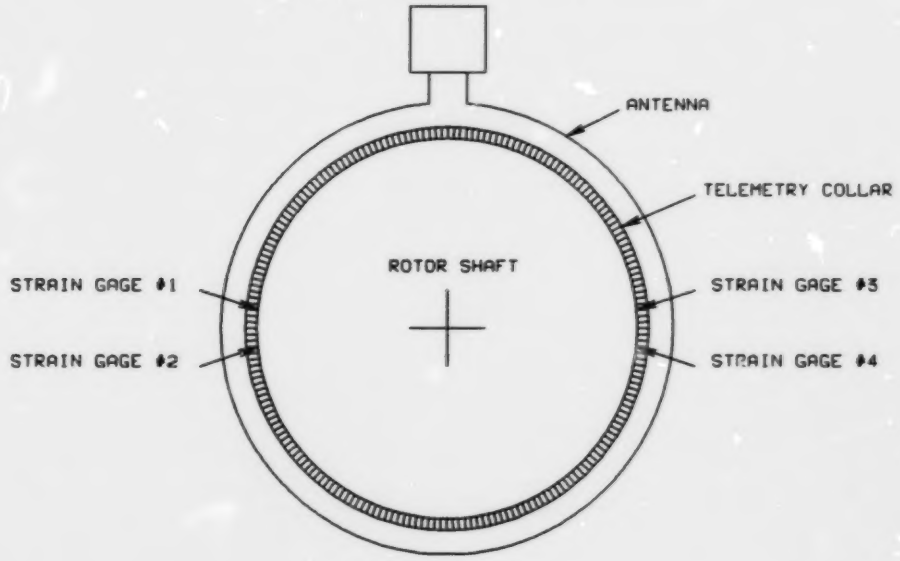


Figure 4: Orientation of Strain Gages on Rotor Shaft

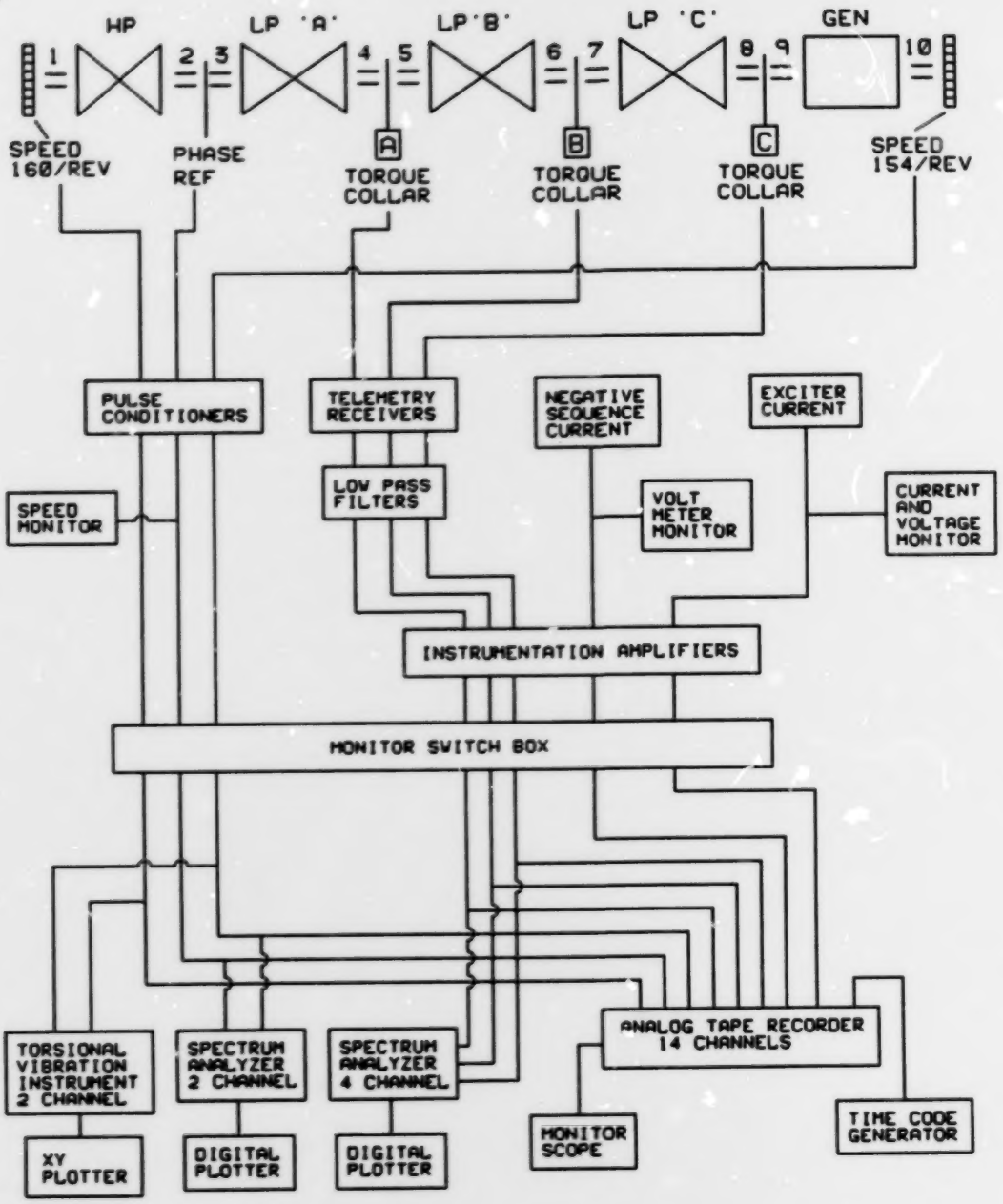


Figure 5: Diagram of Instrumentation Layout

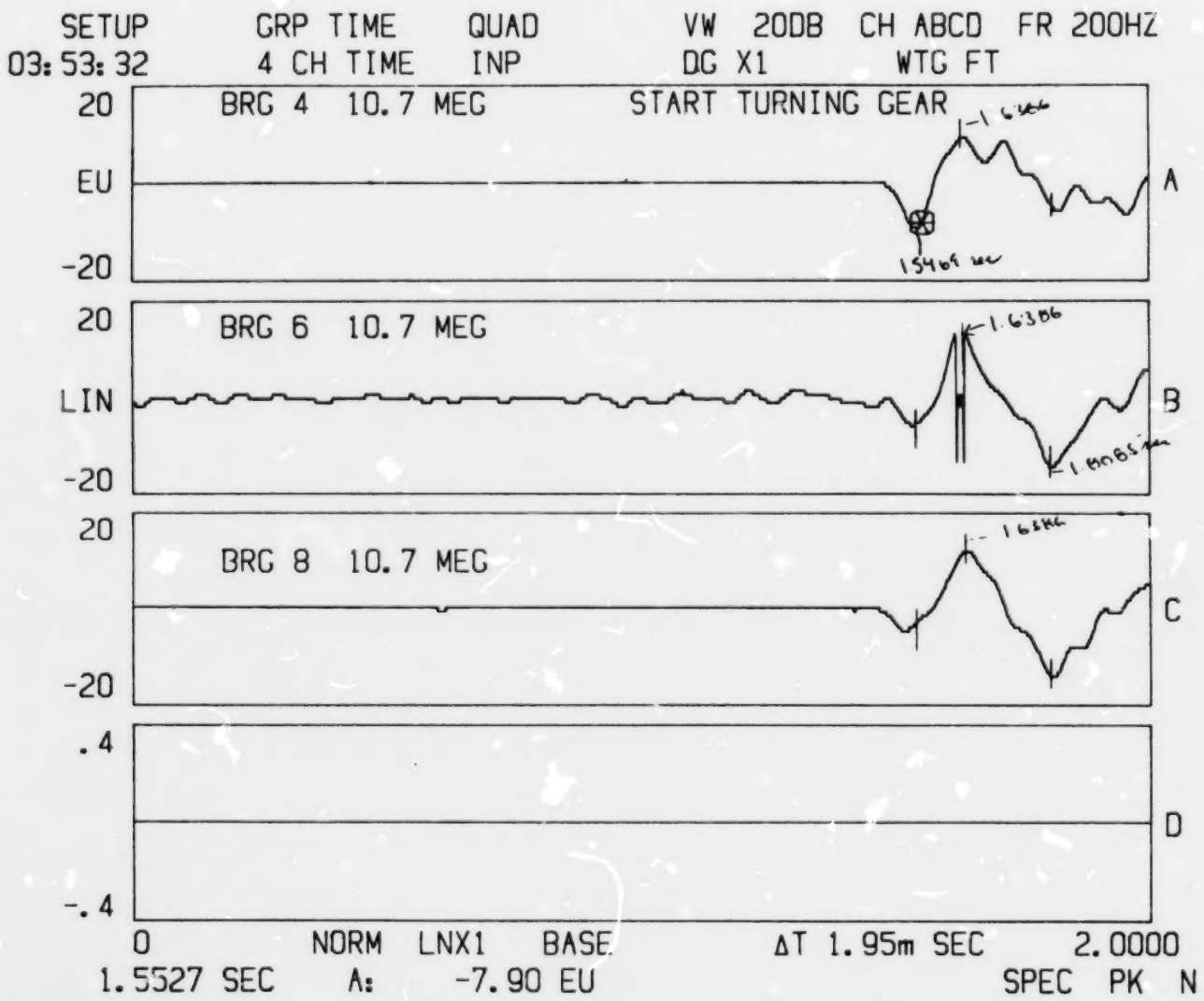


Figure 6: Relative Phase of 10.7 MHz Torque Signals At Turning Gear Start

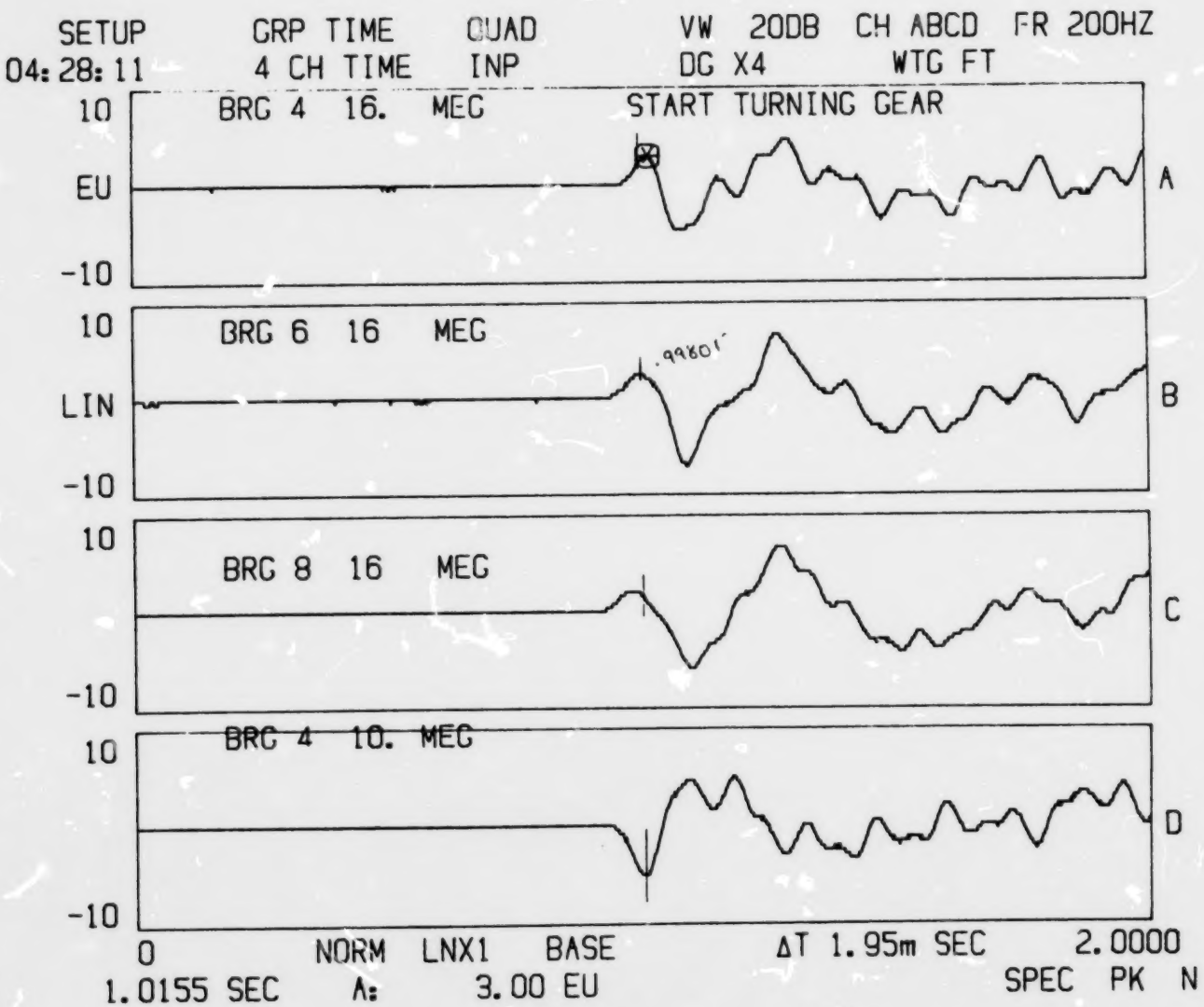
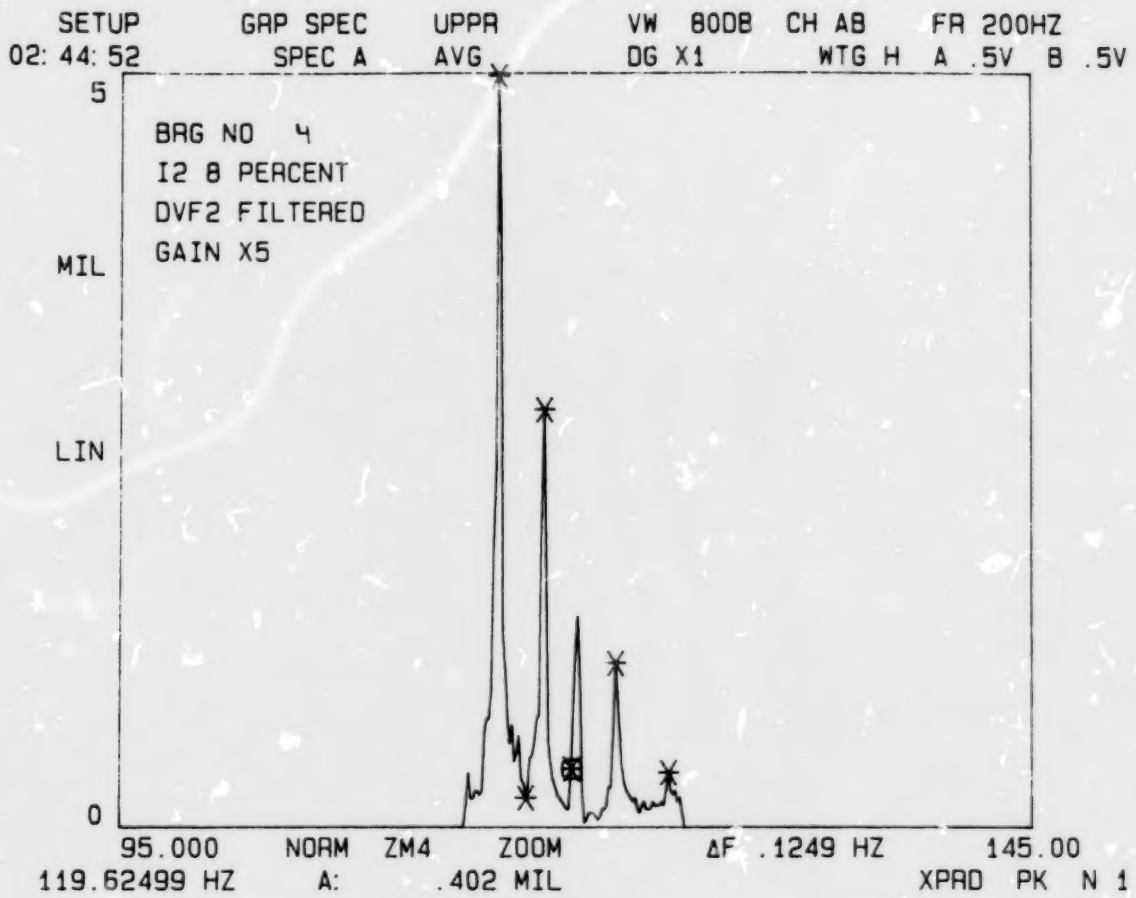
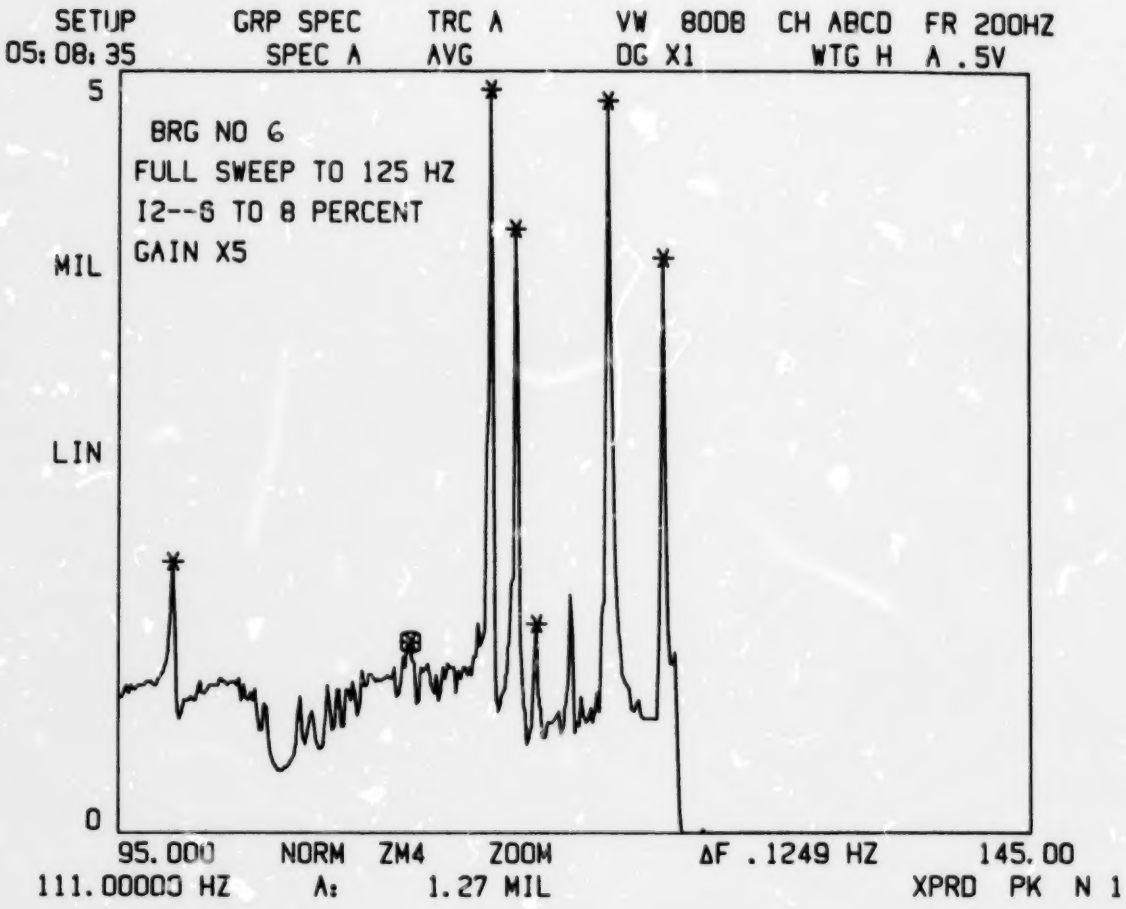


Figure 7: Relative Phase of 16 MHz Torque Signals At Turning Gear Start



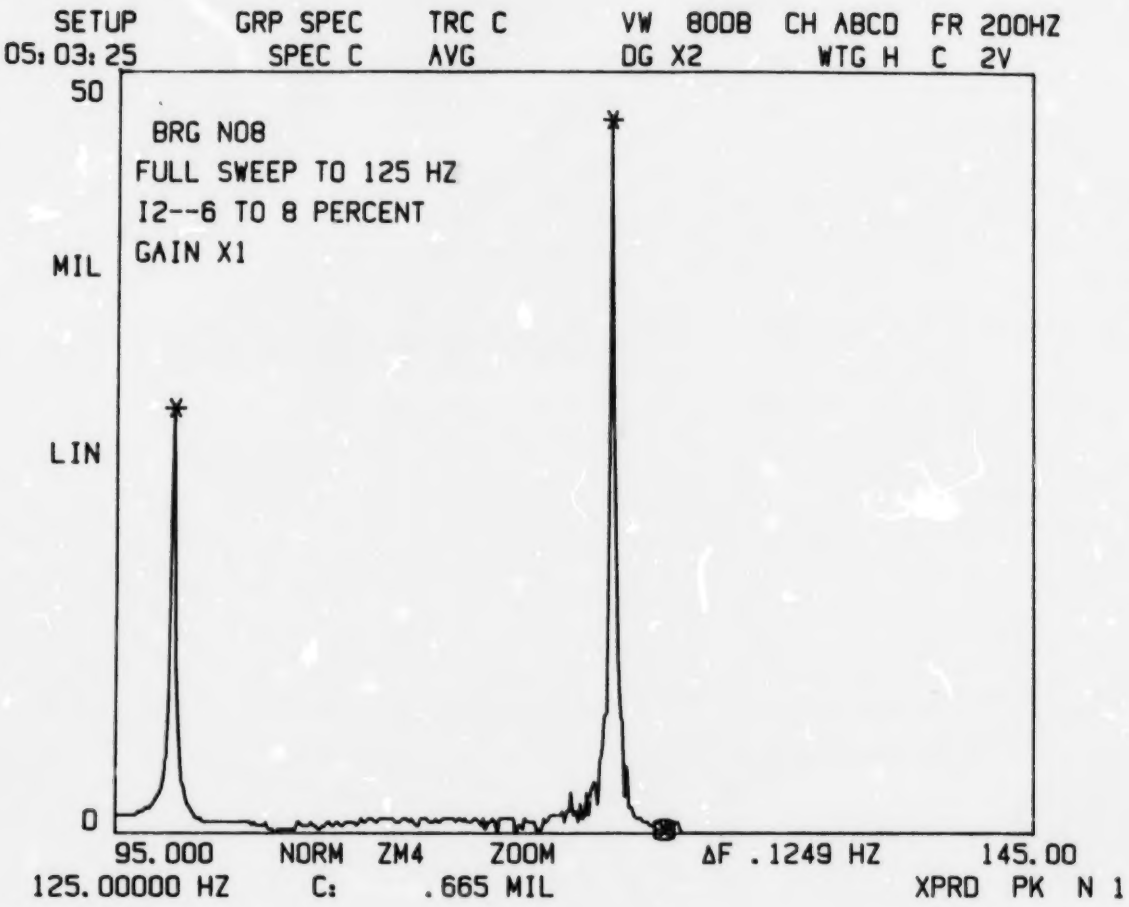
MARK	LIST X	Y
0	115.62499	5.15
1	117.12499	.230
2	118.12499	2.78
3	122.12500	1.12
4	125.12499	.381
5	---	---
6	---	---
7	---	---
8	---	---
9	---	---

Figure 8: Frequency Spectrum of Torsional Strains near Bearing #4


SETUP GRP SPEC TRC A VW 80DB CH ABCD FR 200HZ
05: 08: 35 SPEC A AVG DG X1 WTG H A .5V
5
BRG NO 6
FULL SWEEP TO 125 HZ
I2--6 TO 8 PERCENT
GAIN X5
MIL
LIN
0
95.000 NORM ZM4 ZOOM ΔF .1249 HZ 145.00
111.00000 HZ A: 1.27 MIL XPRD PK N 1

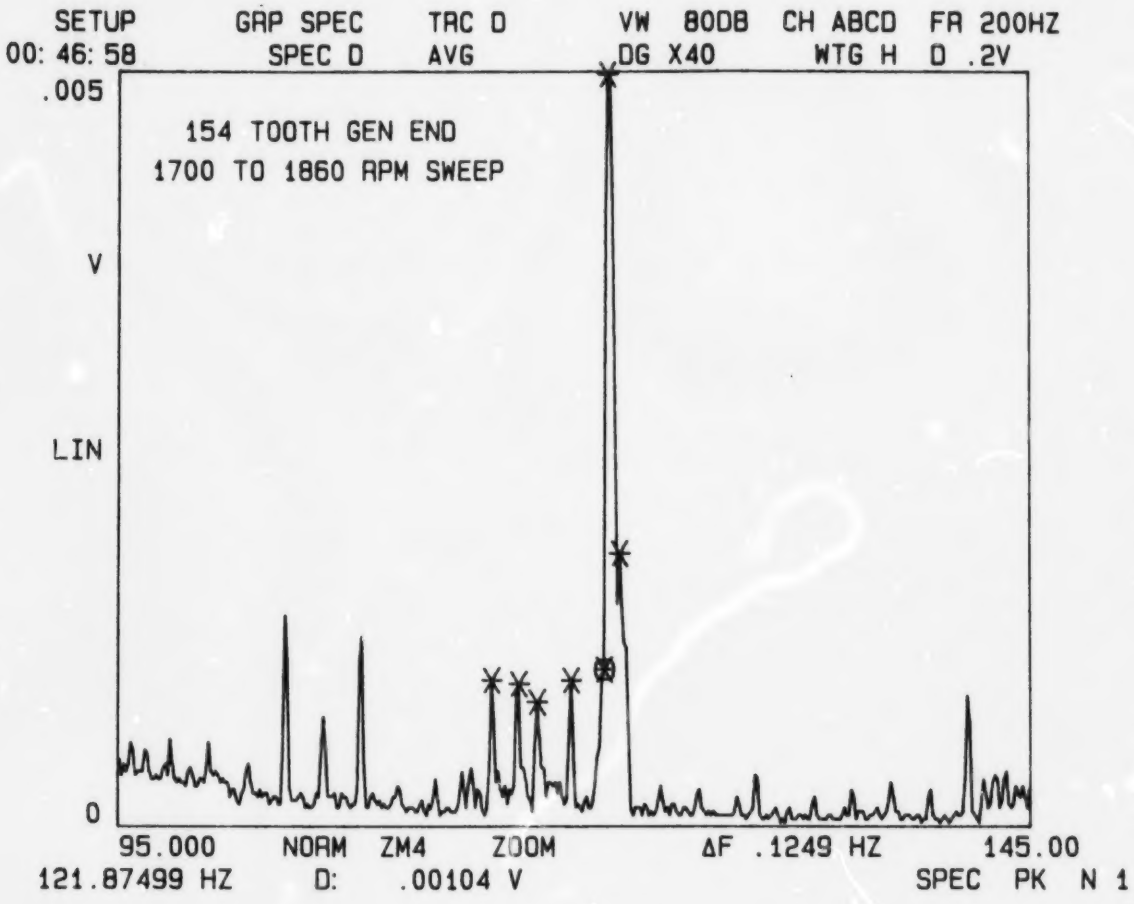
MARK	LIST X	Y
0	98.000000	1.80
1	115.62499	4.92
2	116.99999	3.98
3	118.12499	1.39
4	122.12500	4.84
5	125.12499	3.80
6	---	---
7	---	---
8	---	---
9	---	---

Figure 9: Frequency Spectrum of Torsional Strains near Bearing #6



MARK	LIST X	Y
0	98.124999	28.1
1	122.12500	47.1
2	---	---
3	---	---
4	---	---
5	---	---
6	---	---
7	---	---
8	---	---
9	---	---

Figure 10: Frequency Spectrum of Torsional Strains near Bearing #8



MARK	LIST X	Y
0	115.62499	.0344
1	117.12499	.0338
2	118.12499	.0295
3	120.00000	.0341
4	122.12500	.223
5	122.75000	.0645
6	---	---
7	---	---
8	---	---
9	---	---

Figure 11: Frequency Spectrum of Torsional Signal at Generator Toothed Wheel

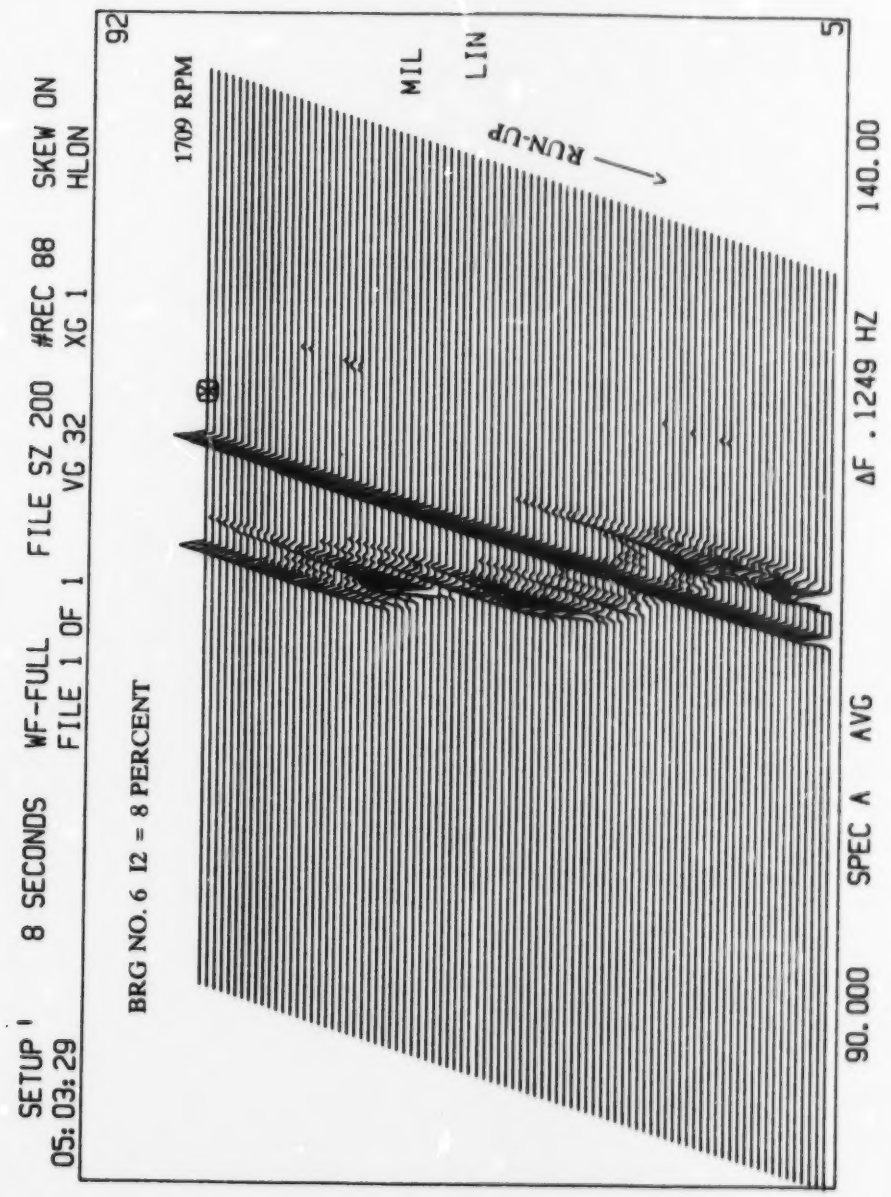


Figure 12: Cascade Plot of Torsional Response near Bearing #6 During Acceleration Test

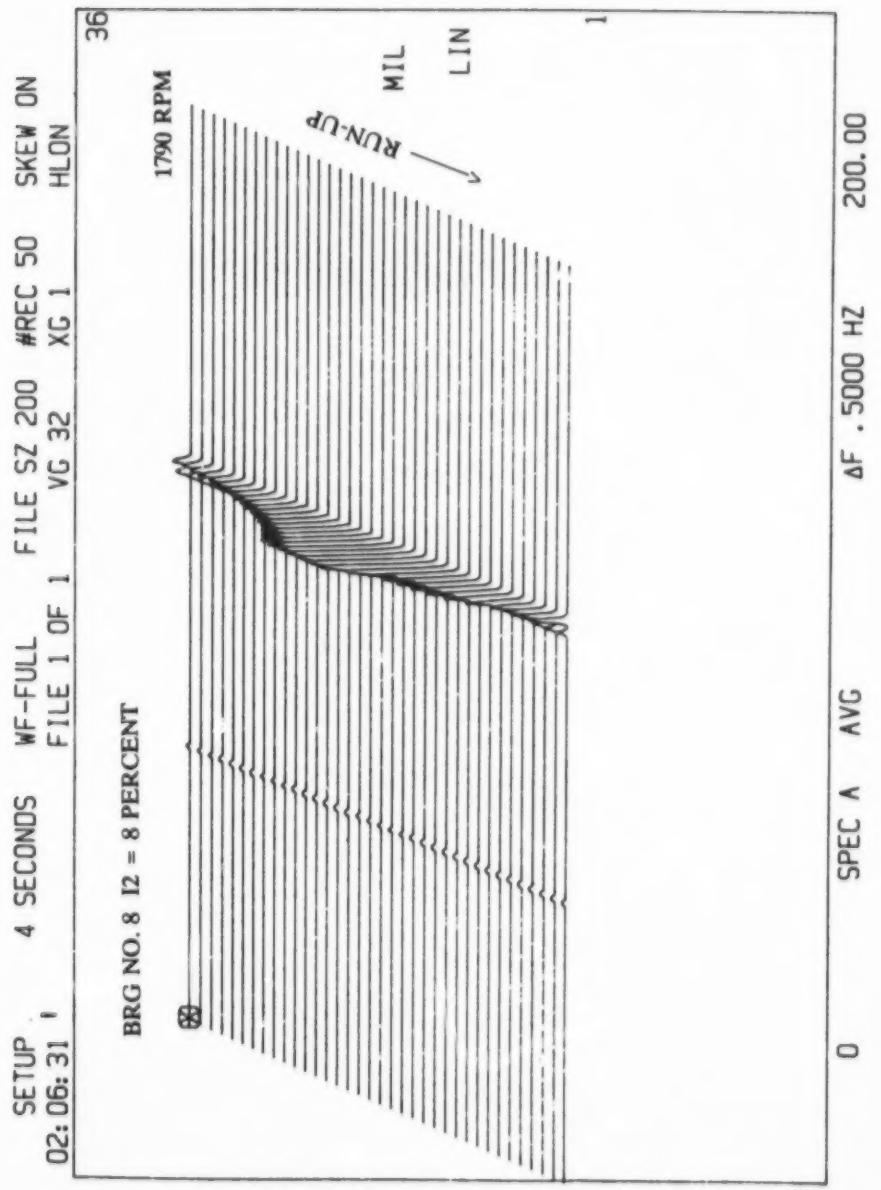


Figure 13: Cascade plot of Torsional Response near Bearing #8 During Acceleration Test

Appendix A

WP 89-6046
T/G TORSION TEST
REVISION 1

DISCARD EARLIER REVISION

APPROVED
B. MOORE

B M Moore 89-10-10

BGB-88

BRUCE NUCLEAR GENERATING STATION "B"
WORK PLAN DATA SHEET

PLAN NO 89-6046 REV 1 UNIT 6 SI 41100
PLAN TITLE T/G TORSIONAL VIBRATION TESTING
PREPARED BY B. DARCY (AUTHOR) VERIFIED BY G Smith (SUPERVISOR) APPROVED BY A SALE (TECH/COMM SUP'T)
COMMISSIONING PROCEDURE NO(S) _____ REV _____
MILESTONE ACHIEVED BY THIS PLAN _____
PREREQUISITES:
Check off all Work Groups to receive a copy of this plan

MT [✓] CT [✓] K1 [✓] S1 [ ] QC [ ] CC [ ] CX [ ] RC [ ] HP [ ] [✓] [ ] [ ]

Unit 1st Op [✓] AECB [✓] Planning [✓] Sh. Sup. [✓]
Outage Co-Ordinator [✓] ASB K1 [ ]

Plan Assessment & Review

1. Unit/Equipment Status (unit outage) (equip. outage) (no outage)
2. Dose Tracking Required YES [ ] NO [✓]
3. High Hazard Plan (See OM 09071.4, Section 1.6) YES [ ] NO [✓]

Type of Hazard
Radiation Electrical Process Other - Specify _____

Check Work Group Required To Review/Assess Plan:

[ ] Health Physics Reviewed _____ Approved _____

[ ] Radiation Reviewed _____ Approved _____

[ ] _____ Reviewed _____ Approved _____
Other - Specify

[ ] Job Director Reviewed _____ Approved _____

_____
Job Director Signature

High hazard procedures have been satisfied _____
Shift Supervisor Signature

4. Work Groups (Check those required to reviewed/assess)

	Time Req'd (Shifts)	Men Req'd	Dose Estim. (m Rem)	Reviewed By	Permit WP	CG	RTP	WP	WORK PC
[✓] Control Mtce.	6-7	2	8		[ ]	[ ]	[ ]		PROT.
[✓] Mechanical Mtce.	6	3			[ ]	[ ]	[ ]	CG	Cond.
[✓] Unit 1st Operator	CAS				[ ]	[ ]	[ ]		GUARAN
[ ] F/H S.O.S.					[ ]	[ ]	[ ]	RTP	RED TAC
[ ] Service Mtce.					[ ]	[ ]	[ ]		PROT.
[ ] Rad. Control					[ ]	[ ]	[ ]		
[ ] Chem. Tech.					[ ]	[ ]	[ ]		
[ ] Quality Control					[ ]	[ ]	[ ]		
N/A Construction					[ ]	[ ]	[ ]		

Work Plan Satisfactory _____ Time Taken Shifts _____
Shift Supervisor Signature

Date Plan Completed by Field _____ Completed By _____ Men Used ___

On Completion Route To:

1. Author

WORK PLAN DATA SHEET - CODES

MT	MECHANICAL MAINTENANCE	CC	CONTROL TECHS. (COMPUTERS)
CT	CONTROL MAINTENANCE	CX	CHEMICAL TECHNICIANS
K1	OPERATORS	RC	RADIATION CONTROL
S1	SERVICE MAINTENANCE	HP	HEALTH PHYSICS

1989-01 (R-13)
ID 75

90-207-K

PLAN 89-6046

TURBINE

TORSIONAL

TEST

BRUCE NGS B

PLAN 89-6046

TURBINE TORSIONAL TEST AT BRUCE NGS B

Revision one October 5, 1989

INTRODUCTION

The attached itemizes the tests to be carried out after the unit outage on unit 6. The co-ordinating workplan is attached to show the exact sequence of events and detailed descriptions are shown in the appendices. There are a few items which were changed from revision zero. Some changes were requested by R. Clarke, Outage Co-ordinator Operator, and some small changes were made in the details of the test procedure dealing with test instrumentation.

The outage start date was October 3/89 and initial torsional test installation work will commence during the outage. The actual test date of November 22 is currently scheduled but this is subject to revision. The modified governor control and test short will be removed and all relaying and exciters will be returned to normal after the test. Test leads, probes, torque collars and TVMS hardware will be removed after the test prior to returning the unit to full power. This will require a shutdown of the turbine generator after the test and access to bearings 4,6 and 8 for removal of torque collars.

Jumper records are required to indicate the modification to the unit excitation, the modification to the governor speed control, the installation of the short on the line, the remote trip on T6H6, the relaying blocked and the probes installed at the bearings.

General Electric Staff from GE Schenectady have requested to visit and witness this test. This has been approved and I will be in touch with S.A. Graziano to advise him of the test date.

O.B. Darcy 4302
Senior Technical Supervisor
Bruce B

RESPONSIBILITIES

BD = B. DARCY
FP = F. PERRICONE
K1,M/M,C/M = STATION STAFF

UNIT 6 TORSIONAL VIBRATION TEST PLAN 89-6046 R-1

NOTE: ITEMS UNDER EACH NUMBER ARE PARALLEL ACTIVITIES.

SEE WRITEUPS IN APPENDICES FOR DETAIL OF THE FOLLOWING AS REQUIRED.

PREREQUISITES TO OUTAGE WORK

1. K1 - Turbine permit in place with T/G shutdown and shaft stationary.

   K1 - Exciter permit on isolating both exciters from the generator field.

   C/M- Exciter mini bus links installed.

   K1- Exciter field breakers open.

   BD+FP-Orange badge for Research Test Staff.

   BD - Setup test table for test equipment.

   BD - Provide 120 VAC at table and at turbine bearings for equipment.

   BD/FP - Obtain welding machine and leads for hookup to exciter cubicle with 4/0 cable.

   BD - Arrange for W. Jardine or J. Morin to be present for test to carry out operation with modified EHC control.

   BD - Setup communications.

   FP - Obtain test leads.

   BD - Receive P and C yardwork details of red phase shorting and discuss with J. Binnendyk. Facility to measure ground fault current to be provided.

FP - Receive test equipment from Research. Including a 250 amp 100 mV shunt for measuring field current. (one week prior to test)

BD - Brief shift staff on test details.

BD - Letter to PSOD requesting confirmation that this is not a system test. This is complete and has been discussed with Transmission Utilization Group. Reply is forthcoming.

BD - Receive updated Relay Sheets from Gord Brooker P and C.

OUTAGE WORK

2. K1 - Isolate Unit Service Transformer. 5314 CB 1B and 5314 CB 1A open.

C/M- Assist Research Staff with cable lead hookups.

C/M- Install EHC mods to governor control.

EMD- Install short on red phase of 29 T6H6 in yard.

P + C - Install remote breaker trip for T6H6.

P + C - Disable relays as on the attached list of generator protections in appendix.

C/M- Install test leads shunt and rectifier from generator PTs and CTs in the relay room. Install cabling from the test location on T/G floor to relay room equipment. (jumper record)

C/M- Obtain welding machine from Research/B. Darcy (Miller deltaweld 650 or similar) and hookup to exciter A field breaker cubicle. Welder is to sit on 639' floor beside test table. Run 4/0 cable (approx. 65 amps max will be required) to exciter A field breaker cubicle from welding machine through floor at brushgear housing. Use suitable lugs for attaching to the buswork. (Note: A modified bracket was used in Unit 8. - see B. Blais). Hookup at AMF- 1B field breaker DWG. 41221-9302 sht 1 item 1216 and 2032. It will be necessary to break the buswork to make the tie in. Note: The positive terminal at the field breaker is the right terminal and the left terminal the negative but this will have to be verified after the unit is shutdown. Connect negative to -N on welder and positive to +P on welder.

Install 250 Amp, 100 mV shunt in cable for current measurement.

Initiate jumper record and tag welder 600 V plug.

NOTE: DO NOT PLUG INTO 600 VOLT SUPPLY UNTIL READY FOR TEST. THIS PLUG IS PART OF THE GENERATOR PROTECTION. INFORM FIRST OPERATOR THAT THIS SHOULD BE ADDED TO THE GENERATOR PERMIT (PC 14)

M/M- T/G bearings 4, 6 and 8 top halves on floor.

Modify bearing top for #4 bearing as per instructions from Research Tech. Holes must be drilled for affixing receiver to top bearing housing before it is put back on turbine.

Modify bearing top for #6 bearing as per instructions from Research Tech. Holes must be drilled for affixing receiver to top bearing housing before it is put back on turbine.

Modify bearing top for #8 bearing as per instructions from Research Tech. Holes must be drilled for affixing receiver to top bearing housing before it is put back on turbine.

3. M/M- Install top half bearing cover for bearing #4.

M/M- Install top half bearing cover for bearing #6.

M/M- Install top half bearing cover for bearing #8.

4. M/M- Assist Research Tech. to install torque strain gauges to shaft on outboard side of Bearing #4. (30 milliwatts spot weld is used). Install torque collars over strain gauges on completion and attach gauge wires to transmitter.

M/M- Assist Research Tech. to install torque strain gauges to shaft on outboard side of Bearing #6. (30 milliwatts spot weld is used). Install torque collars over strain gauges on completion and attach gauge wires to transmitter.

M/M- Assist Research Tech. to install torque strain gauges to shaft on outboard side of Bearing #8. (30 milliwatts spot weld is used). Install torque collars over strain gauges on completion and attach gauge wires to transmitter.

5. C/M- Assist Research Tech. to install test leads, receiver and antenna at bearing #4.

   C/M- Assist Research Tech. to install test leads, receiver and antenna at bearing #6.

   C/M- Assist Research Tech. to install test leads, receiver and antenna at bearing #8.

   C/M- Assist Research Tech. to hookup all bearing test leads to test equipment. Note: test leads must pass through holes in bearing housing. Research Staff are providing cable penetration seals.

6. FP - Test strain gauges and torque collar power supply/ receivers using calibration resistors.

7. M/M- Replace covers on bearings 4, 6 and 8 if equipment tests successful.

   C/M- Hookup test leads from once per rev signal at TJB 2, 160/rev wheel transducer at TJB 1 and the 154 TVMS speed signal transducer (generator end). (jumper records required.)

   160/rev

   In TJB 1 at the front pedestal which will give a 1800 rpm signal of 4800 Hz on a linear scale. Hookup at AN 1, AN 2, AN 3.

   Ref Drawing DIS 64116 - 6003

   1/rev

   This can be picked up at TJB 2 at the front pedestal at terminals BC 10, 11, 12 drawing 64116 - 6002. This is a triangular waveform 30 Hz signal of 1.2 to 4 volts peak to peak.

   154 TVMS

   The 154 TVMS tooth wheel speed pickup can be obtained in PL 5368. Ref Dwg 148D6164 and NK29.D25.64104-9306. The choice of one of 4 probes will be made during installation.

   C/M- Install test leads from exciter supply cable shunt. (jumper record)

8. FP - Setup vibration monitoring equipment and test and calibrate all instrumentation.

   P + C - Test remote breaker trip for T6H6.

9. C/M- Manually close field breaker for exciter A field breaker.

   BD- Issue operating memo for test outlining EHC speed control changes and exciter mods.

PREPARATION FOR STARTUP OF T/G

10. K1- Check unit station service transformer is out of service.

    K1- Check T/G permit removed.

    K1- Check open T6H6, T6H6-H.

    K1- Check short is on at T6H6.

    K1- Check exciter B is isolated from generator with its field breaker open and that the exciter A field breaker is closed with the welder cable lugs affixed to the buswork.

    K1- Check T/G for oil leaks at bearings.

    K1- Check with test leader that all equipment is hooked up and functional.

    K1- Check that remote trip on the generator breaker is functional and ready.

    K1- Check all P and C work is complete and all relaying is as per planning sheets from P and C.

    K1- T/G has been on turning gear for the specified time as per the T/G startup Plan.

    K1- T/G oil flush is completed.

STARTUP

11. FP- With T/G on turning gear verify all signals to test equipment are satisfactory and check that all signals are being recorded.

12. K1- Prewarm T/G as per G. Smith's instructions. Note shell or chest warming are not required at this point as advised by G. Smith.
<u>However, the generator must be heat soaked as per the operating manual prior to exceeding speeds of 1800 RPM. Ref O.M. 41100 sect 4 note 1 which places hydrogen coolers in winter operating mode with one cooler at each end of generator isolated on the LPSW side.</u>

13. K1- Close T6H6 - T (disconnect)

14. K1- Close T6H6 (Generator Breaker) and then do a remote trip test using local pushbutton installed by P and C. On completion reclose breaker.

15. K1- Runup T/G

16. K1- Accelerate T/G to 1800 RPM at 60 RPM/min with TRU (Welding machine 600 volt power supply should be unplugged) Hold speed as required for normal bearing vibration or expansion constraints.

<u>Bearing vibrations must be closely monitored at speeds above 1800 RPM.</u>

17. FP - At 1800 RPM hold speed to allow Research to verify signal recordings.

18. FP - Start tape recorder 3 minutes prior to energizing welding machine.

19. C/M- Plug in the welder to a 600 volt supply and apply minimum field current to test equipment.

20. P+C/FP- Verify that negative sequence current is at approx. 4%.

21. K1/FP- Apply current to field to achieve 6% negative sequence current in generator and record DC amps required.

USE REMOTE TRIP OF T6H6 IF NEGATIVE SEQUENCE CURRENT RISES SHARPLY ABOVE 8%.

P+C- Provide ground current on red phase to test leader

22. K1- Reduce speed to 1500 RPM to commence test.

23. FP - Set 4 channel spectrum analyzer for signature ratio sweep and peak averaging spectra mode. Set 2 channel spectrum analyzer (cepstrum analysis) to measure torsional modes from toothed wheels.

    Setup torsional vibration instrument TV1 to plot torsional vibration mode responses from the toothed wheel signals.

    IF GENERATOR IS PROPERLY HEAT SOAKED PROCEED TO STEP 24.

    NOTE: AT THIS POINT IT IS REQUIRED TO HAVE STABLE BOILER PRESSURE TO ALLOW EXACT SPEEDS TO BE MAINTAINED FOR TESTING. ALL BSRV TESTING OR OTHER WORK WHICH WILL UPSET BOILER PRESSURE MUST CEASE AT THIS POINT.

24. K1+C/M- At 7 RPM/min via EHC modified control, slowly accelerate to 1950 RPM for identification of torsional vibration modes. Use 8% Iz as required if responses are too low. P and C will monitor time spent at 8% to avoid trip.

25. K1- On completion of step 24 and vibration plots are OK reduce speed to 1500 RPM.

26. K1/FP-Go to selected speed holds as requested by Research to take additional test data. We will hold speed precisely at certain speeds to accurately determine torsional vibration data.

    Research staff will set spectrum analyzer to peak mode to measure maximum response and then average mode to measure phase angle.

27. K1+FP- When all data is obtained and is deemed satisfactory reduce field current to zero.

28. K1- Shutdown T/G and <u>DO NOT PUT</u> on turning gear.

29. K1- Apply work protection for opening bearings #4, #6 and #8 to remove test gear, torque collars, TVMS gear and probes at the generator, for removal of all test leads, for removal of the short in the switchyard and for returning the EHC system to normal operation.

30. EMD- Electrical Maintenance remove short in switchyard.

P+C- Restore all normal generator protection.

C/M- Restore EHC to normal.

C/M- Remove welding machine cables and restore buswork in exciter A to normal. Open field breaker manually.

P+C- Remove remote trip on generator breaker.

M/M- Open T/G bearings 4, 6 and 8 to allow removal of torque collars and instrumentation. Also remove TVMS gear and speed probes from generator.

M/M+FP- Remove torque collars and strain gauges from bearings 4, 6 and 8.

IT IS NOT INTENDED TO DO ANOTHER FLUSH AFTER THE TORQUE COLLARS AND BRACKETS ARE REMOVED, THEREFORE, IT IS EXTREMELY IMPORTANT TO ENSURE THAT SWARF DOES NOT ENTER THE OIL SYSTEM AND THAT GRINDING OF TACK WELDS IS NOT DONE.

31. M/M- Replace all bearing covers and retorque.

32. K1- Remove T/G permit and exciter permit.

33. K1- Put T/G on turning gear and bar until eccentricity is satisfactory for runup. G. Smith will likely be around to advise. 24 hours barring time is expected.

34. K1- Heat soak generator as per OM and apply shell and chest warming as for normal T/G startup.

35. K1- Energize exciters.

36. K1- Runup T/G for overspeed tests. Monitor normal T/G vibrations during startup.

37. K1- Load unit as required if O/S tests are successful and Technical Unit - G. Smith satisfied with condition of T/G.

38. K1+C/M+M/M- Return completed plans to Technical and cancel appropriate jumpers applied during test.

39. BD- Cancel operating memos.

APPENDIX

TURBINE
GENERATOR ROTOR SYSTEM TORSIONAL SCREENING TEST AT BRUCE 'B' UNIT 6 X 821

BACKGROUND

The Manshaan Unit #1 turbine was believed to have failed because of high cycle fatigue of the turbine LP B last stage buckets at 120.5 Hz resonant response or 60.25 Hz electrical system frequency. This fatigue was due to the excitation of a very high torsional mode of vibration of the rotor system.

Historically only the lower torsional modes of vibration were considered during turbine design, usually up to 6 or 7 modes. GE, however can now analyze over 20 modes of vibration and have developed instrumentation to verify analytical results.

Because calculation alone is not precise enough to determine exact values of torsional frequencies close to 120 Hz it was recommended to perform a test on a Bruce NGS 'B' machine in order to determine if a resonant response exists at or near operating frequency. The results of this torsional vibration test on unit 8 and tests on unit 6 will dictate the appropriate course of action. Such action could be detuning by the addition of weight to the rotors or by installing a frequency/negative phase sequence current relay (I_2) which will trip the turbine if operation in a critical range is occurring.

Inspection of the last stage blade dove tails is also recommended. This will be completed during the shutdown. Inspection and testing of units 5 and 7 has not been planned. An assessment of this will be made after the test results on unit 6 are analyzed and comparisons are made to the unit 8 results.

TEST DESCRIPTION

The purpose of the test is to determine the precise location of the turbine-generator rotor system torsional resonant frequencies near operating speeds. The test is recommended to ensure that there is adequate separation between possible resonant frequencies occurring near 120 Hz and dynamic torques also occurring at 120 Hz.

The rotor torsional natural frequencies and damping of sub and super-synchronous modes of vibration will be measured. This will be accomplished on runups from approx. 1500 RPM to 1950 RPM.

To measure the torsional frequencies an appropriate torsional stimulus must be applied to the shaft system. This is accomplished by making electrical and mechanical measurements of the shaft when it is excited torsionally as follows.

1. During a slow ramp from 1500 RPM to 1950 RPM.
2. During selected frequency holds.
3. A load rejection and/or an out of phase synchronization will NOT be completed on unit 6.

SINGLE PHASE TEST

A solid line to neutral short will provided on the red phase of the line in the switchyard on the line side of 29 T6H6 such that the short can be isolated by opening 29 T6H6. The short will be isolated from the line via the line disconnect 29 T6H6-H which will be open and T6H6-T will be closed. This short circuit will provide the required negative phase sequence current required for the test.(I_2).

The exciter banks of the generator will be isolated and a welding machine will be substituted to excite the windings. Such an arrangement gives the fine control required during the test.

During this test the level of response in the rotors will be closely controlled such that 6% I_2 will not be exceeded. If the response level approaches set limits the excitation will be reduced to zero. If the response still continues to exist the breaker 29 T6H6 can be opened quickly from the test site to eliminate the short.

The modified governor control and test short will be removed and all relaying and exciters will be returned to normal after the test. Test leads, probes and torque collars will be removed after the test prior to returning the unit to full power. Also, this includes removal of the TVMS 154 tooth wheel on the generator and the associated hardware at the generator. This will require a shutdown of the turbine generator after the test for access to the bearings for removal of torque collars.

OPERATION OF UNIT DURING TESTS

Bruce NGSB Production Unit staff will operate the turbine for all testing and will act on request from the test leader (Frank Perricone - Hydro Research) via the station test leader (Bruce Darcy). During the slow speed ramp test T/G speed control will be via a modification at the Governor (EHC) panel. This speed control will be carried out by C/M personnel from the CER under the Unit First Operator's direction.

The Generator must be heat soaked before the rotor speed is taken above 1800 RPM and bearing vibrations must be closely monitored at speeds above 1800 RPM.

Frank Perricone will work closely with B. Darcy to establish each test point.

Both must be notified before any change in operating condition is initiated. A 5 second countdown is required before any test initiation or change of test condition.

TEST PREREQUISITES

1. All test equipment is to be on site one week prior to the test commencememt date of NOV 22/89. It should be contained in lockable cabinets or containers until required or it can be put into T/G stores in the stores trailer on the 639 elevation. Bearing support brackets have been fabricated by Bruce B M/M and are ready for the test.

2. A test table will be made available during the outage to allow hookup of leads and equipment. An in plant telephone is also being provided for use at the test location as well as two earphone connection points for using the plant maintenance phone system during the test.

3. Selected members of the test team will be "orange badged" at the start of the installation so that plant access is simplified. The time required for the orange badge training is approximately two hours.

4. The turbine work protection must be such that:

   The T/G shaft does not have to be turned during the torque collar installations as access to install the instrumentation is adequate with the shaft stationary. Therefore, jacking oil and lube oil will not be required. All test equipment will be installed after turbine alignments are completed prior to bearing boxup.

   A permit will be required for the isolation of both exciters and for connection of the test leads and welding cables at the field breaker. This can be part of the T/G permit if desired.

   EMD Staff will make separate application for the required work in the switchyard.

P and C Staff will make separate application for relaying to be blocked and for hookup of the remote breaker trip.

It will be necessary to isolate the unit station service transformer 6-5212-TSS61 A and B windings for the test via 5314 - CB 1B and 5314 - CB 1A.

5. P + C and EMD have advised us of details of the yardwork, relays to be disabled and updated relay sheets. The red phase will be shorted as was done for unit 8.

6. BNGSB C/M will modify the EHC control to give 7 RPM/min speed rate. This can be installed at any time during the outage. As it is a temporary modification and outside of the governor cubicle the unit must be shutdown after the shorted phase testing so that it can be removed.

7. All cabling runs can be laid out during the outage at a convenient time. P. Hoogendam from Research will be present as required to assist with these hookups from the relay room and the T/G bearings.

   THE CABLES FOR THE TEST LEADS WILL BE PROVIDED BY RESEARCH STAFF.

   Gord Brooker P and C will provide the remote breaker trip for 29 T6H6 and the cabling run from the Unit 6 Relay Room.

8. A welding machine capable of 300 amps DC at 25 volts will be provided at the test location on the turbine floor with leads running to the field breaker cubicle of exciter A.

   P. Hoogendam will investigate obtaining a Miller Deltaweld 650 welding machine or similar which will have minimum "ripple" on the DC output. A station welding machine (Hobart Mega-Flex 650 RVS) was used in Unit 8 but some ripple was evident. Note: A minimum of 57 amps DC in Unit 8 gave 5% I_2. Approx. 65 amps DC. was used to attain the 6 - 8% I_2 required.

   The tie in will be made at the buswork when the unit is shutdown by disconnecting the buswork and bolting the welding leads to the buswork upstream of the exciter A field breaker in the cubicle. No other disconnections are required in the exciter but both exciter A and B will be isolated from the generator during the test. Only the exciter A field breaker will be used and the field current from the welder will pass through it.

9. A signal from the 1/rev wiring, a speed signal from the 160/rev toothed wheel and a signal from the 154 toothed wheel (TVMS) will be utilized.

10. Station Mechanical Maintenance and Control Maintenance staff will be required to assist Research Staff for the installation of probes and test gear prior to the testing. It will require 3 days at 12-14 hrs per day to install the hardware based on actual experience in unit 8. Welding will be required to install some of the test hardware. Research Staff will consist of 2 Test Engineers and 2 Technicians.

11. The communications to be used will be the plant maintenance telephone system. This system will allow voice communication via headsets from the test location to numerous locations including the control room, control equipment room, the switchyard, the relay room and any other area if desired. A telephone will also be available at the test location.

12. Shift operators will co-ordinate permits, communications and operator related work as required.

<u>WORK PRIOR TO THE TEST DURING UNIT OUTAGE</u>

1. Isolate the unit 6 generator 29G6 from the grid and open disconnects 29T6H6-H (lineside of 29 T6H6) and close 29 T6H6-T.

2. Isolate the unit station service transformer 6-5212-TSS61 A and B windings via 5314 CB 1B and 5314 CB 1A. Provide unit 6 station service from the system service transformer 29 TSS 6.

3. EMD to install the solid line to neutral short on the red phase of the line in the switchyard between 29 T6H6 and 29 T6H6-H. They will provide for 300 amps at the short and will be required to measure and record this current during the test. (Actual current from unit 8 was 182 amps). The actual current value is to be passed to test leader when measured.

4. P + C to disable relaying as shown in attached listing from P and C. The bulk of generator protection will remain in service as indicated in the attached listing.

   NOTE: The I_2 (negative phase relay) will be in service for the test at its normal current settings. This will allow 8% I_2 for short periods as per the chart provided by P and C. If it is necessary to exceed the time as shown at 8% I_2 this relay will have to be disabled.

   Note: The 8% value was not required in unit 8 for longer than a few minutes and this was closely monitored by P and C. P and C Staff will also monitor the time spent at the 8% I_2 trip level during the Unit 6 test.

   The PALC microprocessor being developed for future I_2 trip relays will also be installed to checkout its operation. G. Brooker P and C will install on "A" Protective Relaying during the outage in conjunction with Research Staff.

5. Operators to isolate normal excitation (exciter A and B) from the generator. A welding machine (650) will be used to excite the generator and the leads will be installed at the upstream side of the exciter A field breaker between the blocking diodes and the field breaker. This is required so that the field breaker can disconnect the DC field current if required during the test. Cabling will be run from the welding machine, located near the turbine brushgear, to the field breaker cubicle so that control of the field will be at the test location.

   Instrumentation leads (provided by Research Staff) will be run from the welding machine supply cable shunt to allow measurement of field current and voltage. This shunt is to be provided by Research to measure the current flowing to the sliprings. see figure 1

6. Generator phase current and generator terminal voltage can be measured at the metering circuits in the unit 6 relay room on the 663' elevation. This is used for direct readout of the I_2 current for the test.

   The following CT and PT links are available as per figure 4A.

CT's	Red	4121G1 - TL 99
	White	4121G1 - TL 100
	Blue	4121G1 - TL 101
PT's	Red	4121G1 - FU 48
	White	4121G1 - FU 49
	Blue	4121G1 - FU 50

   Ref drawing NK 29 DIS 64121-6008 (R 18)

   NOTE: Research will be installing a rectifier circuit and a shunt on the red phase to suit their equipment.

   The leads from this will run through the 663' floor in the relay room and to the test desk on the 639' elevation.

7. The generator negative sequence current I_2 will be measured via the Research test equipment and by P and C Staff in the relay room.

8. Torsional displacements in the front standard will be measured at the toothed wheel (160/rev). This speed signal will be transmitted to the test instrumentation.

   This signal can be picked up at the following location:

   In TJB 1 at the front pedestal which will give a 1800 rpm signal of 4800 Hz on a linear scale. Hookup at AN 1, AN 2, AN 3.

   Ref Drawing DIS 64116 - 6003

9. The once per rev. signal phase reference probe is to be provided to test instrumentation. This can be picked up at TJB 2 at the front pedestal at terminals BC 10, 11, 12 drawing 64116 - 6002. This is a triangular waveform 30 Hz signal of 1.2 to 4 volts peak to peak.

10. The 154 TVMS tooth wheel speed pickup can be obtained in PL 5368. Ref Dwg 148D6164 and NK29.D25.64104-9306. The choice of one of 4 probes will be made during installation. SCN for probe pickup is 619C5802.

11. The bearing top halves can be installed and torqued down as convenient prior to torque collar installation.

    Mechanical Maintenance will be required to leave the bearing covers off of bearings 4, 6, and 8 so that work can proceed on the brackets for torque collar receiver installation. **ALSO, RESEARCH STAFF MUST TUNE THE ANTENNAE BEFORE THE COVERS ARE REPLACED.**

    M/M will be required to drill and tap the 2 required holes in the bearing top halves when they are on the floor. They will be required to tack weld the torque collar brackets after they are fitted to the bearings and will be required to assist Research Staff to install the hardware.

    THE BEARING TOP HALVES WILL BE ON THE FLOOR FOR WELDING AND DRILLING OPERATIONS TO ENSURE THAT SWARF DOES NOT ENTER THE OIL SYSTEMS. THIS WILL BE COMPLETED DURING THE OUTAGE WHEN THE BEARINGS ARE REMOVED FOR INSPECTION.

12. Telemetry torque collars to measure torsional dynamic strains on the shaft journals will be installed on bearings 4, 6 and 8 outboard sides.

    These collars are installed as shown on GE drawing 155D5070. The antenna brackets are bolted to the side of the bearing into the eyebolt lifting holes and are tack welded to hold them in place. Weld Spec. P 123. The strain gauges are tack welded to the shaft by Research Technicians and are covered by torque collars. The collars are sealed with a RTV product and are fixed to the shaft with RTV. The axial location of the torque collar and the antennae will be determined by Research Staff. The LP shafts will grow approx. 1/2" towards the generator with thermal expansion. This will be allowed for in placement of the torque collars. The antennae support brackets were designed by GE so that the torque collars or antennae do not interfere with existing station monitoring equipment.

    The 2 holes previously drilled and tapped into the top side of the bearings are for mounting of the torque collar power supply units. The antennae and power supply units will be installed after the torque collars are fitted using the brackets made by M/M (DR FI 884). The installation will then be checked prior to closing the bearing housings.

One hole must be drilled through the bearing outer casing lower half, at each torque collar location, for lead wire penetration to the external electronics. Drill and tap this hole 1/4" NPT. This will be done on the lower half of the outer casing near the half joint so that the leads are protected. Research will provide the penetration seals and the cabling through the penetration. These penetrations will be plugged after the torque collars and cabling are removed. The cabling from the receivers outside of the bearing housing to the test location will be provided by Research. Two pairs of wires (4 wires) are required at each torque collar location.

13. Install a switch at the test location which will be used to remotely trip the HV breaker 29 T6H6 inboard of the short if it is required to terminate the test under emergency conditions. This switch will be wired into panel 159 in the relay room by E and C staff.

    This will still allow operation of the breaker from the control room by the unit operator.

BEARING WORK AND LUBE OIL CLEANLINESS

1. THE BEARING TOP HALVES WILL BE REMOVED FOR WELDING AND DRILLING OPERATIONS WHERE PRACTICAL TO ENSURE THAT SWARF DOES NOT ENTER THE T/G OIL SYSTEM.

2. THE BEARINGS AND JOURNAL AREAS ARE TO BE COVERED IMMEDIATELY AFTER REMOVAL OF THE TOP HALF BEARING.

3. IMMEDIATELY AFTER THE TEST AND PRIOR TO RETURNING THE UNIT TO FULL POWER THE T/G WILL BE SHUT DOWN TO REMOVE THE TORQUE COLLARS. THIS WILL REQUIRE BREAKING OF THE TACK WELDS AT THE BEARINGS TO REMOVE THE HARDWARE AT THE BEARING BOTTOM HALVES. (DO NOT GRIND) THE OIL CLEANLINESS SUPERVISOR IS TO ENSURE THAT PROPER BARRIERS AND COLLECTORS ARE IN PLACE TO PREVENT SWARF FROM ENTERING THE LUBE OIL SYSTEM.

4. PRIOR TO THE INITIAL T/G STARTUP AFTER THE UNIT OUTAGE A 24 HOUR FLUSH WITH FINE MESH STRAINERS WILL BE REQUIRED TO ENSURE THAT THE OIL SYSTEM IS FREE OF DEBRIS.

   IT IS NOT INTENDED TO DO ANOTHER FLUSH AFTER THE TORQUE COLLARS AND BRACKETS ARE REMOVED. THEREFORE, IT IS EXTREMELY IMPORTANT TO ENSURE THAT SWARF DOES NOT ENTER THE OIL SYSTEM AND THAT GRINDING OF TACK WELDS IS NOT DONE.

APPENDIX -- OUTSTANDING ITEMS

The details of this test have been included here based on the premise that we will only be placing torque collars on bearings 4, 6 and 8 for this test. Other requirements such as cabling, speed pickups etc. have not been identified to station staff by Research Division Staff. The following is a list of concerns some of which have been answered.

1. How will negative phase sequence current be measured apart from P and C manually calculating this during the test.
Ans. Research Staff will provide instrument.

2. Will all the hookups on the plan be necessary and will Research provide the cabling required.
Ans. Research Staff will provide cabling. The required hookups have been identified by Research Staff.

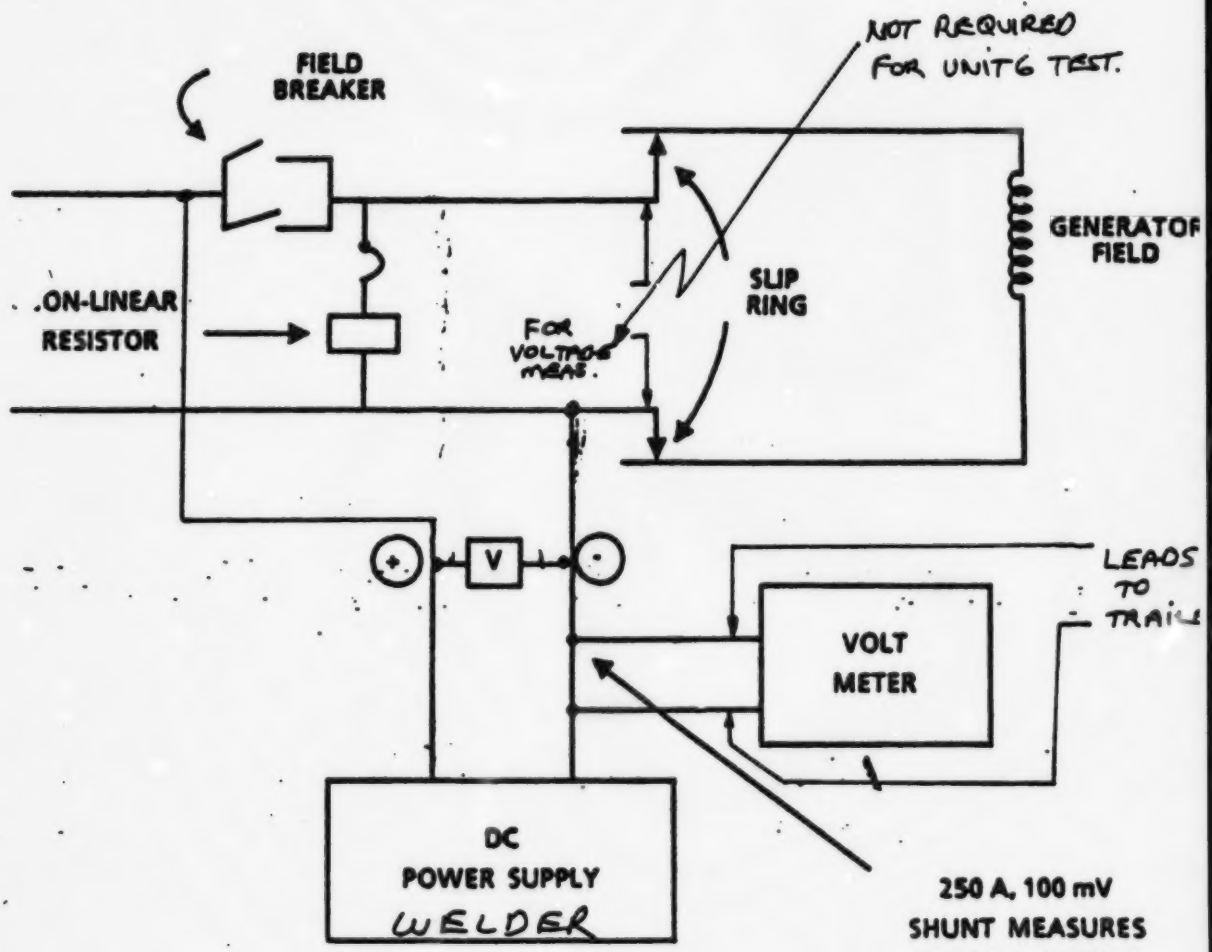
3. Will the test be a strict check of the torsional frequencies of concern from the unit 8 test. I am assuming a runup from 1500 RPM at 7 RPM/MIN to 1950 RPM.
Ans. Yes.

4. I am assuming that 6% to 8% negative sequence current will be used exclusively for testing. Anything less than this complicates the hookup of the welding machine.
Ans. Yes.

5. The means of fixing the antennae and receiver unit for the torque collars has not been communicated to me. I assume that it is the same as for the GE test.
Ans. yes. Research Staff have requested that Bruce fabricate the brackets. This has been done.

6. A detailed step by step procedure of Research Division's procedure and requirements has not been received by the station. As a result it is necessary to issue the plan as attached. Violent deviations from this procedure will likely not be acceptable, particularly if outage delays will result.
Ans. Received and incorporated in plan. A meeting was held Oct 3.89.

FIGURE 1
TORSIONAL VIBRATION TEST
EXCITATION DIAGRAM

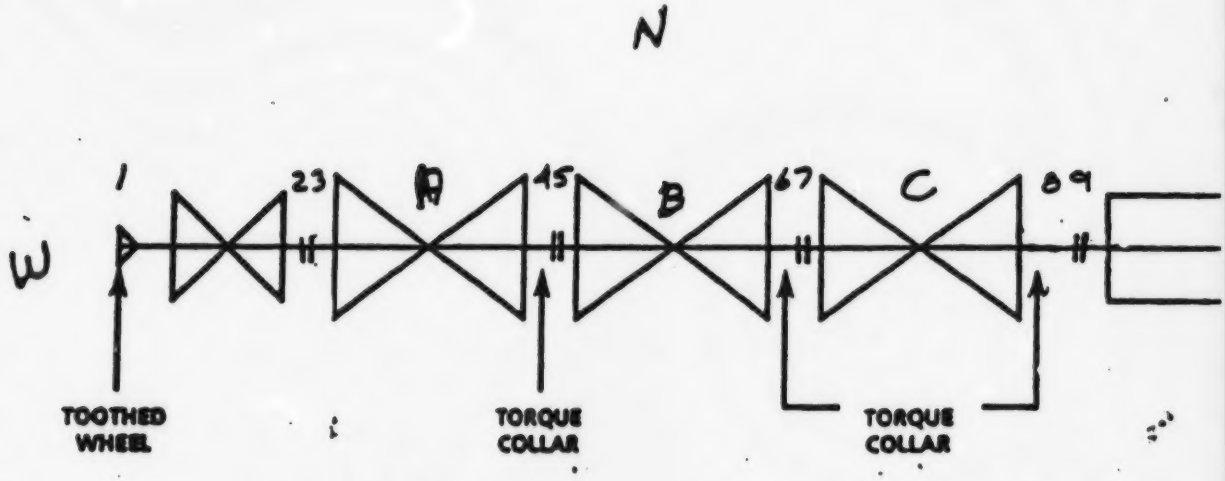


V = VOLT METER

FIGURE 2

TORSIONAL VIBRATION TEST

INSTRUMENTATION



BRUCE 'B' UNIT 6 TORSIONAL VIBRATION MONITORING

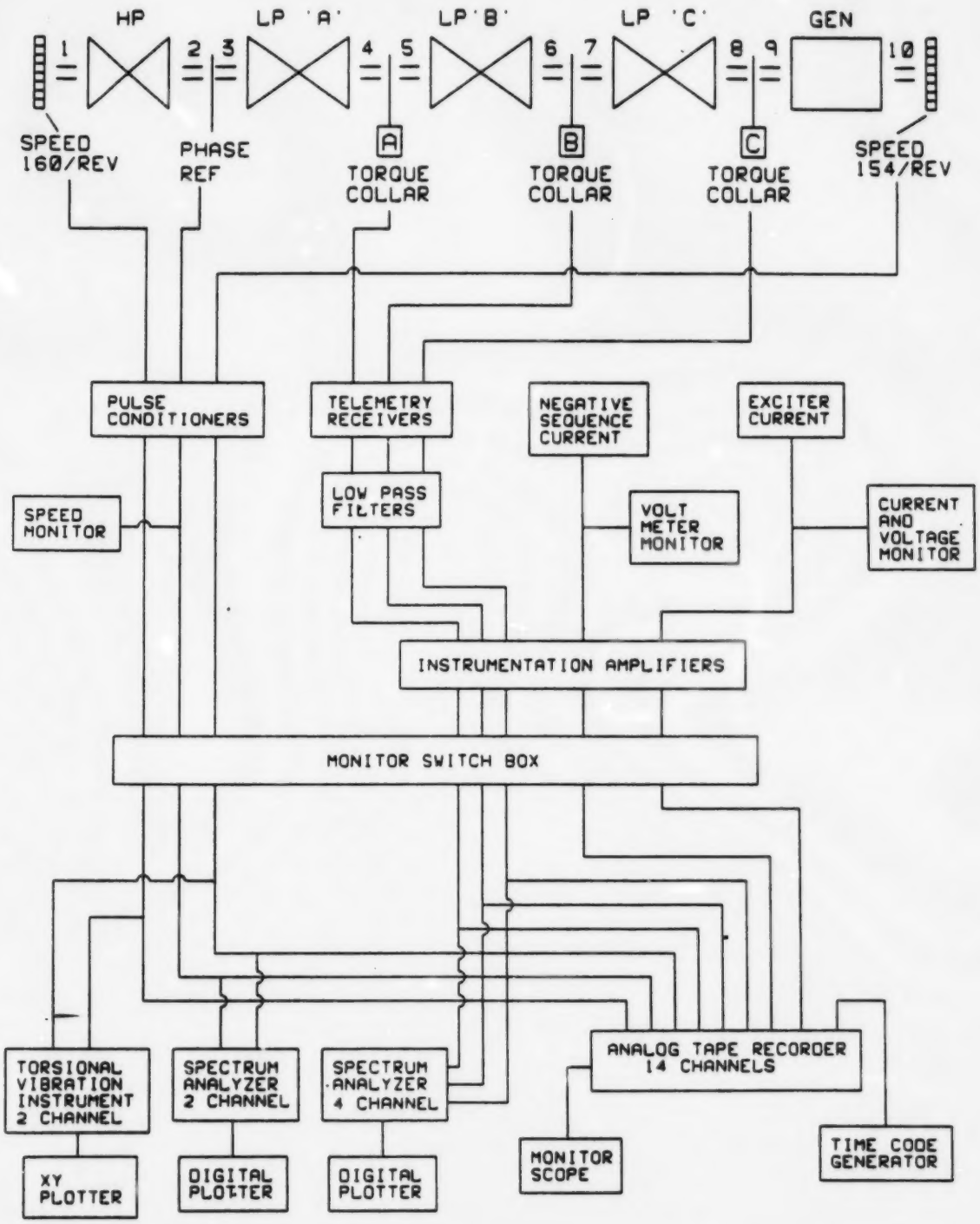
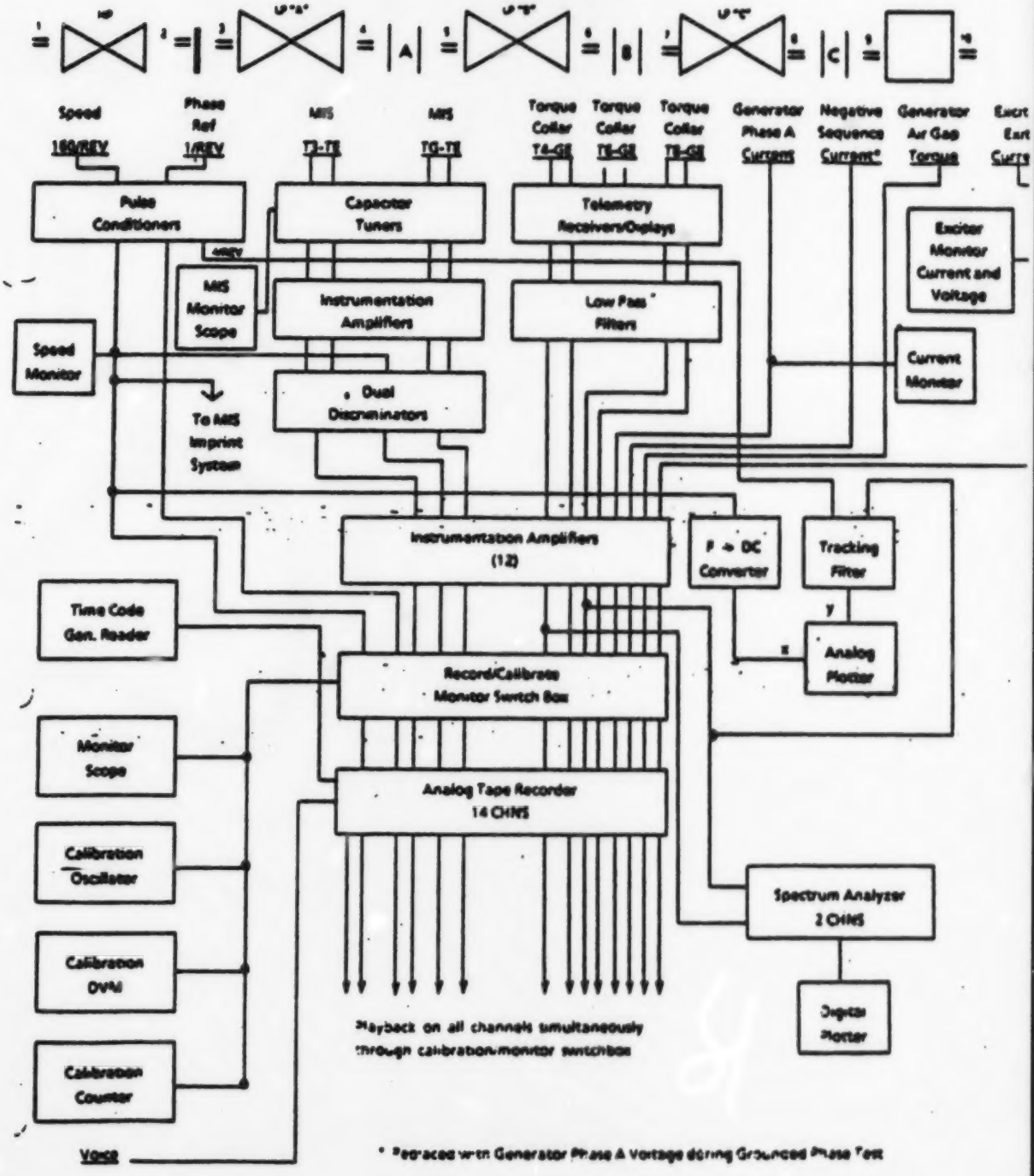


Figure 3

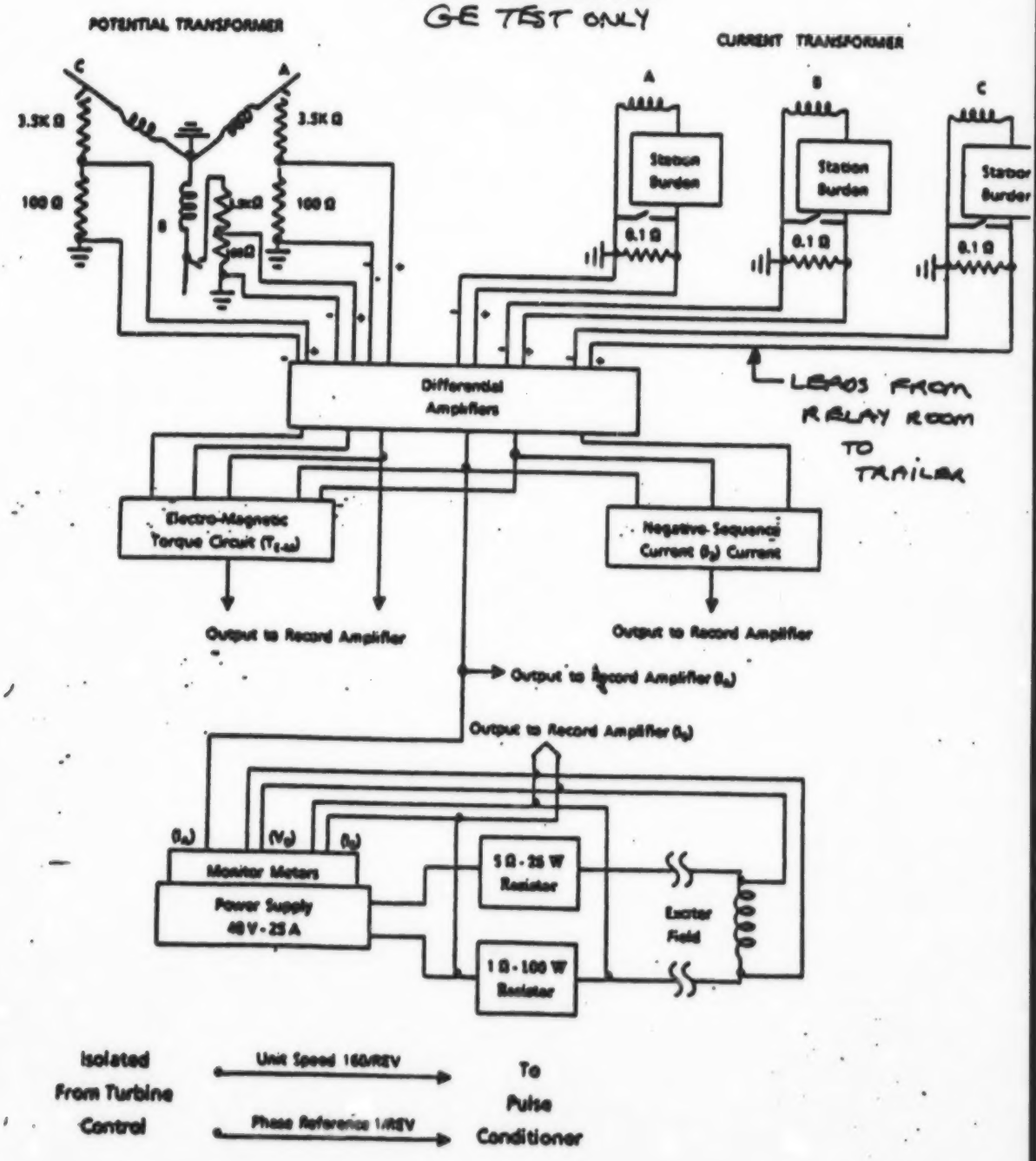
FOR GE TEST SETUP ONLY

FIGURE 3
TORSIONAL VIBRATION TEST
INSTRUMENTATION BLOCK DIAGRAM
(6-FLOW UNIT)



BNGS 'B'

FIGURE 4A
TORSIONAL VIBRATION TEST
STATION INSTRUMENTATION
GE TEST ONLY



BRUCE B #1 BASE CASE - ORIGINAL ROTORS
TORSIONAL RESPONSE LIMITS FOR
DAMPING OF 0.50 % AND 80 % FATIGUE STRENGTH

ROTOR SHEAR STRAIN LIMITS (P-P)

	FREQ.	BRG #4	BRG #6	BRG #8
	(Hz)			
2	49.6	30.238	3.744	-36.967
3	51.1	61.426	-50.931	-37.499
4	52.6	-74.776	-86.705	-27.313
5	66.4	3.108	2.540	-2.779
6	66.4	3.048	4.640	-2.535
7	66.5	-6.670	6.762	-3.032
8	74.7	22.589	-18.871	0.860
9	75.6	8.884	-28.829	1.701
10	76.8	-42.626	-34.976	2.747
11	96.7	6.972	93.314	981.094
12	111.6	-1.623	23.002	110.199
13	111.6	-2.149	25.457	109.441
14	111.6	-2.270	25.743	107.962
15	112.0	50.593	-210.617	-13.517
16	112.7	-129.514	-92.745	-14.113
17	113.4	-103.756	-60.601	-12.736
18	115.9	93.716	103.143	14.111
19	117.5	-37.160	54.991	29.755
20	118.9	-46.102	4.461	39.379
21	121.4	7.744	-35.734	118.130
22	123.4	-3.606	27.709	145.429
23	125.6	-2.933	112.895	18.435
24	127.8	7.513	2.156	123.934
25	130.8	13.977	7.820	5.042
26	131.5	-32.744	-21.763	18.726

BRUCE B #1 BASE CASE - ORIGINAL ROTORS
TORSIONAL RESPONSE LIMITS FOR
DAMPING OF 0.50 % AND 80 % FATIGUE STRENGTH

ROTOR SHEAR STRAIN LIMITS (P-P)

	FREQ. (HZ)	LOC. 25 1st T	LOC. 43 2nd T	LOC. 61 3rd T	LOC. 0 4th T	LOC. 0 5th T	LOC. 0 6th T	TOT (1.(
2	7.5	-1430.589	-1494.228	-685.496	0.	0.	0.	0.(
3	14.3	1531.901	-785.619	-1130.829	0.	0.	0.	0.
4	19.6	-466.419	1146.119	-1348.174	0.	0.	0.	0.
5	22.4	-287.849	136.957	-80.725	0.	0.	0	1.(
6	49.6	30.238	3.744	-36.967	0.	0.	0.	1.:
7	51.1	61.426	-50.931	-37.499	0.	0.	0.	0.(
8	52.6	-74.776	-86.705	-27.313	0.	0.	0.	1.
9	66.4	3.108	2.540	-2.779	0.	0.	0.	8.:
10	66.4	3.048	4.640	-2.535	0.	0.	0.	6.(
11	66.5	-6.670	6.762	-3.032	0.	0.	0.	7.(

43.00 in. BKT T.E. STRAIN 0. in. FROM ROOT (1E-6 p-p)

FREQ. (HZ)	LPA-TE	LPA-GE	LPB-TE	LPB-GE	LPC-TE	LPC-GE	TORQ LIM 1.E6 in-lb
7.5	14[illegible] 917	136.569	38.654	14.966	-83.838	-102.993	0.080
14.3	-166.928	-111.709	271.508	289.793	92.194	22.809	0.148
19.6	40.799	-8.115	-231.777	-179.231	365.226	337.642	0.181
22.4	104.922	144.604	-48.036	-60.222	28.719	33.440	1.006
49.6	-307.237	291.059	355.823	-362.318	-231.777	264.121	1.272
51.1	347.693	-362.033	96.463	-52.697	-310.509	318.287	0.918
52.6	-173.024	196.607	-348.656	361.728	-298.986	278.180	1.170
66.4	-201.684	-207.445	-286.216	-286.512	-260.365	-252.208	8.265
66.4	286.323	281.718	-75.349	-79.017	-260.307	-258.563	6.054
66.5	-167.118	-155.149	286.078	280.729	-219.660	-227.973	7.063

28.30 in. BKT T.E. STRAIN 0. in. FROM ROOT (1E-6 p-p)

FREQ. (HZ)	LPA-TE	LPA-GE	LPB-TE	LPB-GE	LPC-TE	LPC-GE	TORQ LIM 1.E6 in-lb
7.5	111.712	104.576	27.156	13.468	-65.238	-76.307	0.080
14.3	-120.581	-89.129	206.018	216.432	63.037	23.517	0.148
19.6	25.856	-1.478	-167.959	-138.596	269.829	254.415	0.181
22.4	81.513	103.393	-36.752	-43.471	21.729	24.332	1.006
49.6	-114.642	105.265	130.094	-133.861	-81.760	100.510	1.272
51.1	118.937	-126.912	38.004	-13.668	-106.744	111.070	0.918
52.6	-53.529	66.009	-111.408	118.328	-98.832	87.822	1.170
66.4	27.174	27.519	38.273	38.284	34.505	34.008	8.265
66.4	-38.949	-38.661	10.372	10.597	35.498	35.387	6.054
66.5	23.015	22.255	-39.980	-39.635	31.172	31.695	7.063

RPM vs. CPS vs. 4/Rev FREQUENCY

TOR S	SPEED RPM	4/Rev FREQ.,Hz	% SPEED	ROTOR CPS	SPEED RPM	4/Rev FREQ.,Hz	% SPEED
0.00	0	0	0.00	27.50	1650	110	91.67
0.50	30	2	1.67	28.00	1680	112	93.33
1.00	60	4	3.33	28.50	1710	114	95.00
1.50	90	6	5.00	29.00	1740	116	96.67
2.00	120	8	6.67	29.25	1755	117	97.50
2.50	150	10	8.33	29.50	1770	118	98.33
3.00	180	12	10.00	29.75	1785	119	99.17
3.50	210	14	11.67	30.00	1800	120	100.00
4.00	240	16	13.33	30.25	1815	121	100.83
4.50	270	18	15.00	30.50	1830	122	101.67
5.00	300	20	16.67	30.75	1845	123	102.50
5.50	330	22	18.33	31.00	1860	124	103.33
6.00	360	24	20.00	31.50	1890	126	105.00
6.50	390	26	21.67	32.00	1920	128	106.67
7.00	420	28	23.33	32.50	1950	130	108.33
7.50	450	30	25.00	33.00	1980	132	110.00
.00	480	32	26.67	33.50	2010	134	111.67
.50	510	34	28.33	34.00	2040	136	113.33
9.00	540	36	30.00	34.50	2070	138	115.00
9.50	570	38	31.67	35.00	2100	140	116.67
10.00	600	40	33.33	35.50	2130	142	118.33
10.50	630	42	35.00	36.00	2160	144	120.00
11.00	660	44	36.67	36.50	2190	146	121.67
11.50	690	46	38.33	37.00	2220	148	123.33
12.00	720	48	40.00	37.50	2250	150	125.00
12.50	750	50	41.67	38.00	2280	152	126.67
13.00	780	52	43.33	38.50	2310	154	128.33
13.50	810	54	45.00	39.00	2340	156	130.00
14.00	840	56	46.67	39.50	2370	158	131.67
14.50	870	58	48.33	40.00	2400	160	133.33
15.00	900	60	50.00	40.50	2430	162	135.00
15.50	930	62	51.67	41.00	2460	164	136.67
16.00	960	64	53.33	41.50	2490	166	138.33
16.50	990	66	55.00				
17.00	1020	68	56.67				
.50	1050	70	58.33				
18.00	1080	72	60.00				
18.50	1110	74	61.67				
19.00	1140	76	63.33				
19.50	1170	78	65.00				
20.00	1200	80	66.67				
20.50	1230	82	68.33				
21.00	1260	84	70.00				
21.50	1290	86	71.67				
22.00	1320	88	73.33				
22.50	1350	90	75.00				
23.00	1380	92	76.67				
23.50	1410	94	78.33				
24.00	1440	96	80.00				
24.50	1470	98	81.67				
25.00	1500	100	83.33				
25.50	1530	102	85.00				
26.00	1560	104	86.67				
.50	1590	106	88.33				
27.00	1620	108	90.00				

Customer: Ontario Hydro
Station: Bruce B #8
Shop Order: 180X824

Generator:

Rating (MVA)	980.000
Armature voltage (KV)	24.
Synchronous reactance, Xd	1.8424
Negative sequence reactance, X2i	0.2659
Air gap amperes (1.0 pu)	1179.0
Field resistance (50 deg. C)	0.1105
Negative sequence current level (%)	8.00
Required field current (A)	238.6
Field voltage for above current (V)	26.37
Required exciter field current (A)	0.
Air gap torque at rated speed (pu)	0.00610
Air gap torque at rated speed (in-lbf)	280694.
Rated generator torque (in-lbf)	46015582.
Maximum phase voltage (KV)	1.087
Voltage across shorted phase (KV)	0.809
Armature current in shorted phase (A)	3266.7

Transformer:

Rating (MVA)	825.000
Rated voltage, low side (KV)	22.8
Rated voltage, high side (KV)	525.
Leakage reactance on gen. base (pu)	0.1404
Ground current (A)	245.7
Maximum phase voltage (KV)	21.744

Detailed phase voltages (per unit):

	A		B		C	
	Mag	Ang	Mag	Ang	Mag	Ang
Generator	0.0480	143.	0.0762	0.	0.0480	-143.
Transformer	0.0000	90.	0.0682	-14.	0.0682	-166.

October 10, 1989

SUBJECT: TORTIONAL VIBRATION TEST
H.V. EQUIPMENT PROTECTION SUMMARY
PROTECTION AND CONTROL
CENTRAL WHOLESALE REGION

A) PROTECTIONS TO REMAIN IN-SERVICE DURING TORSIONAL VIBRATION TEST

1) -GENERATOR "A" DIFFERENTIAL TRIP
-RELAY A87-R28
-PROTECTS AGAINST PHASE TO PHASE AND THREE PHASE FAULTS WITHIN ZONE
-PICKUP SETTING 10% DIFFERENTIAL WITH 10% RESTRAINT SLOPE
-CLASS "A" TRIP

2) -GENERATOR "B" DIFFERENTIAL TRIP
-RELAY B87-R72
-PROTECTS AGAINST PHASE TO PHASE AND THREE PHASE FAULTS WITHIN ZONE
-PICKUP SETTING 10% DIFFERENTIAL WITH 10% RESTRAINT SLOPE
-CLASS "A" TRIP

3) -GENERATOR PHASE OVERCURRENT PROTECTION
-RELAY A50S-R53
-NORMALLY PROTECT AGAINST PHASE OVERCURRENT DURING START-UP. THIS PROTECTION WILL BE IN SERVICE FOR ALL TESTS. REF. JUMPER TAG #ABE866
-PICKUP SETTING AT 4800 A IN GENERATOR STATOR WINDING.
-CLASS "A" TRIP

4) -GENERATOR OVEREXCITATION PROTECTION
-RELAY A59L-R43 AND A59H-R140
-PROTECTS AGAINST EXCESSIVE HIGH FLUX IN MAGNETIC CIRCUIT.
-LOW SETTING AT 428 V/HZ + 45 SEC Vb-w. REF JUMPER TAG #ABE867
-HIGH SETTING AT 472 V/HZ + 2 SEC Vb-w. REF JUMPER TAG #ABE867
-TRIPS EXCITATION BKRS. 6-4122CB1 / CB2 ON LOW SETTING.
-CLASS "A" TRIP ON HIGH SETTING.

5) -GENERATOR GROUND PROTECTION
-RELAY B64N-R74
-PROTECTS AGAINST GROUND FAULTS IN THE GENERATOR WINDINGS
-PICKUP SETTING 693 V AT 60 HZ + 1 s PRIMARY ON NEUT. DIST. TRANS.
-CLASS "A" TRIP

6) -GENERATOR GROUND PROTECTION ON START UP
-RELAY A64S-R54
-PROTECTS AGAINST GROUND FAULTS DURING STARTUP. THIS PROTECTION WILL REMAIN IN SERVICE FOR ALL TESTS. REF JUMPER TAG #ABE866
-PICKUP SETTING 140v AT 15 Hz +1 s PRIMARY ON NEUT. DIST. TRANS.
280v AT 30 Hz +1 s PRIMARY ON NEUT. DIST. TRANS.
560v AT 60 Hz +1 s PRIMARY ON NEUT. DIST. TRANS.
-CLASS "A" TRIP

7) -GENERATOR NEGATIVE PHASE SEQUENCE / PHASE UNBALANCE PROTECTION
-RELAY B46-R100

-PROTECTS AGAINST ROTOR OVERHEATING DUE TO NEG. PHASE SEQ. CURRENT.
-PICTUP SETTING 1920 A NEG. PHASE SEQ. CURRENT ON GENERATOR WINDINGS.
-CLASS "A" TRIP.

8) -TRANSFORMER T6 "A" AND "B" PROTECTIONS.
-CLASS "A" TRIP

9) -TURBINE GENERATOR MECHANICAL TROUBLE TRIP

2) PROTECTIONS TO REMAIN OUT OF SERVICE DURING TORSIONAL VIBRATION TEST.

1) -GENERATOR LOSS OF EXCITATION TRIP
-RELAY A40B-R52 AND A40A-R133
-OPEN BLOCKING SWITCHES 6-4121G1-BS19A / BS20A REF JUMPER TAG #ABE868

2) -GENERATOR UNDER FREQUENCY PROTECTION ON STARTUP
-RELAY A81S-R57
-REMOVE FUSES 6-4121G1-FU19 / FU20 REF JUMPER TAG #ABE867
-JUMPER A81S-R57 RELAY TERMINAL 1 AND 2. REF JUMPER TAG #ABE866

3) -GENERATOR FIELD OVERVOLTAGE PROTECTION
-RELAY A59F-R170
-REMOVE FUSES 6-4121G1-FU77 / FU78 REF JUMPER TAG #ABE867

4) -GENERATOR UNDERFREQUENCY PROTECTION
-RELAY B81L-R89
-OPEN BLOCKING SWITCHES 6-4121G1-BS17B / BS19B REF JUMPER TAG #ABE868

5) -GENERATOR OUT OF STEP PROTECTION
-RELAY B21-78z-R106 AND B21-78-R108
-OPEN BLOCKING SWITCHES 6-4121G1-BS17B / BS19B REF JUMPER TAG #ABE868

6) -GENERATOR GROUND PROTECION
-RELAY A64N-R31
-OPEN BLOCKING SWITCH 6-4121G1-BS12A REF JUMPER TAG #ABE868

GORD BOOKER
PROTECTION AND CONTROL
tortvib.gab

Mr. B. Darcy
Bruce N.G.S."B"

Please review the following notes and the attached table and notify Protection & Control personnel if any changes to the tests will be made as a result of this information.

NOTE!
The Negative Sequence current relay setting is based on the original generator rating of 895 MVA. The relay is set at 8% of 21500 Amperes which corresponds to a negative sequence current (I2) of 1720 Amperes.

NOTE!
The Turbine Torsional Test description indicates a possibility of approaching a Negative Phase Sequence Current of 8% during one of the tests using Generator rating of 980 MVA (23575 Amperes). This is equivelant to a Negative Phase Sequence current of 1888 Amperes. If this value of Negative Phase Sequence current is reached the protection will trip the generator in approximately 15 minutes.

E. M. DOBROWOLSKI
P&C ENGINEER
G.B.R.

c.c.
C. Bromley
I. Franke
B. Kenyon

DATE: APR 8,1987

TURBINE TORSIONAL TESTS AT BRUCE "B"

Relay Type: ABEA RARIO
Protection: Generator Phase Unbalance (Negative Phase Sequence)
Location: Unit 8 Relay Room, Panel 128
Ref. Dwg.: 64121-6828 and 64121-6844

RELAY SETTING: NEGATIVE PHASE SEQUENCE CURRENT (I2)

ALARM (ANN#972 WINDOW# 1D-41)- 5% (1875 A) OF FLA (21500 A) + 4.5 SECONDS
TRIP +ALARM (ANN#966 WINDOW# 1D-22)- 8% (1720 A) OF FLA (21500 A) + TIME

XI2 895 MVA RATING	XI2 900 MVA RATING	PHASE CURRENT AMPERES	NEG Ø CURRENT AMPERES	GROUND CURRENT AMPERES	TIME TO TRIP MINUTES (+/- 10%)	GEN C.T. CURRENT AMPERES	A.C. VOLTS RELAY 187 (3,15-4,25)	REMARKS
1.3%	1.2%	500	289	38	NO ALARM, NO TRIP	0.07	0.46	
1.5%	1.3%	550	318	41	NO ALARM, NO TRIP	0.07	0.51	
1.6%	1.5%	600	347	45	NO ALARM, NO TRIP	0.08	0.56	
1.7%	1.6%	650	376	49	NO ALARM, NO TRIP	0.09	0.60	
1.9%	1.7%	700	405	53	NO ALARM, NO TRIP	0.09	0.65	
2.0%	1.8%	750	434	56	NO ALARM, NO TRIP	0.10	0.70	
2.2%	2.0%	800	462	60	NO ALARM, NO TRIP	0.11	0.74	
2.3%	2.1%	850	491	64	NO ALARM, NO TRIP	0.11	0.79	
2.4%	2.2%	900	520	68	NO ALARM, NO TRIP	0.12	0.83	
2.6%	2.3%	950	549	71	NO ALARM, NO TRIP	0.13	0.88	
2.7%	2.5%	1000	578	75	NO ALARM, NO TRIP	0.13	0.93	
2.8%	2.6%	1050	607	79	NO ALARM, NO TRIP	0.14	0.97	
3.0%	2.7%	1100	636	83	NO ALARM, NO TRIP	0.15	1.02	
3.1%	2.8%	1150	665	86	NO ALARM, NO TRIP	0.15	1.07	
3.2%	2.9%	1200	694	90	NO ALARM, NO TRIP	0.16	1.11	
3.4%	3.1%	1250	723	94	NO ALARM, NO TRIP	0.17	1.16	
3.5%	3.2%	1300	751	98	NO ALARM, NO TRIP	0.17	1.21	
3.6%	3.3%	1350	780	101	NO ALARM, NO TRIP	0.18	1.25	
3.8%	3.4%	1400	809	105	NO ALARM, NO TRIP	0.19	1.30	
3.9%	3.6%	1450	838	109	NO ALARM, NO TRIP	0.19	1.34	
4.0%	3.7%	1500	867	113	NO ALARM, NO TRIP	0.20	1.39	
4.2%	3.8%	1550	896	116	NO ALARM, NO TRIP	0.21	1.44	
4.3%	3.9%	1600	925	120	NO ALARM, NO TRIP	0.22	1.48	
4.4%	4.0%	1650	954	124	NO ALARM, NO TRIP	0.22	1.53	
4.6%	4.2%	1700	983	128	NO ALARM, NO TRIP	0.23	1.58	
4.7%	4.3%	1750	1012	131	NO ALARM, NO TRIP	0.24	1.62	
4.8%	4.4%	1800	1040	135	NO ALARM, NO TRIP	0.24	1.67	
5.0%	4.5%	1850	1069	139	ALARM, NO TRIP	0.25	1.72	--LEVEL DETECTOR ALARM UNIT PICKE
5.1%	4.7%	1900	1098	143	ALARM, NO TRIP	0.26	1.76	
5.2%	4.8%	1950	1127	147	ALARM, NO TRIP	0.26	1.81	
5.4%	4.9%	2000	1156	150	ALARM, NO TRIP	0.27	1.86	
5.5%	5.0%	2050	1185	154	ALARM, NO TRIP	0.28	1.90	
5.6%	5.1%	2100	1214	158	ALARM, NO TRIP	0.28	1.95	